TRANSACTIONS

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American Society for Steel Treating

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RESEARCH AND INDUSTRY

THE advances made in scientific research during recent years have been most encouraging. Technically trained men and women have been delving into the study of Nature's laws for the purpose of definitely determining their correlation one to the other. Much progress has been made in all branches of science and many practical applications have resulted which have vastly improved our living conditions and our worldly happiness.

Scientists have given unsparingly of their time and energy in the study of various problems in which they are particularly interested and as a result have in many instances brought forth truths which have been of vast importance in our economic existence.

It is within the memory of many, that some of the large corporations were loath to recognize the value of research and as a result were unwilling to lend much financial aid unless it was clearly demonstrated to them that some tangible return could be made. It is gratifying to know that this situation no longer exists and that many companies throughout the world have been very generous in assisting scientists to solve their problems by contributing financial aid, moral support and encouragement. The support which these large companies and corporations give to their scientific staffs is not necessarily for their own financial gain, because there are many times when lines of research are pursued and when ultimately completed have little bearing upon the specific line of endeavor of a particular organization. Indirectly perhaps, this line of research may be of service in solving some one problem, but we know of many cases where the cost for carrying

through a given investigation has far exceeded the financial return from it.

The generosity expressed by many of these large corporations in disseminating information and publishing the results of researches is a most commendable attribute. A specific example of this generosity is demonstrated in this issue of TRANSACTIONS in the paper by Francis F. Lucas, entitled, "The Microstructure of Austenite and Martensite," wherein his company has contributed many thousands of dollars in assisting him to carry through his microscopic researches on the structure of metals. They have supplied him with much costly special apparatus for conducting his investigations and have devoted much money to the publication of his findings.

WINTER SECTIONAL MEETING

AS announced in the November issue of TRANSACTIONS, the Winter Sectional Meeting of the Society will be held in Cincinnati, under the auspices of the chapter, the dates chosen being Thursday and Friday, January 15th and 16th, 1925, with headquarters at the Hotel Sinton.

The program for this meeting is as follows:

Thursday, January 15th

10:30 A. M.—Registration
11:00 A. M.—Technical Session
12:30 P. M.—Luncheon, Hotel Sinton
2:00 to 5:00 P. M.—Technical Session
6:30 P. M.—Banquet

Friday, January 16th

Plant Visitation

This is the first sectional meeting held in Cincinnati, and the Committee on Arrangements has assured us that a most interesting program has been arranged so that this sectional meeting will be equal or even better than any of the previous sectional meetings held by the Society. The technical papers program will be very comprehensive, consisting of five papers. A complete list of speakers will be announced in the January issue of TRANSACTIONS.

The Cincinnati meeting is one of the two sectional meetings to be held next year and gives those members living in the general region of Cincinnati the opportunity to get together for a renewal

of acquaintance and the exchange of ideas. It is hoped that every member will make an effort to be present at this meeting.

VOLUME VI OF TRANSACTIONS COMPLETED

THIS issue of TRANSACTIONS completes Volume VI, which covers the period from July, 1924, through December, 1924. Volume VII will include the period from January, 1925, through June, 1925. The index for Volume VI is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume VI bound in accordance with the style used in binding Volumes I, II, III, IV and V, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

REPORT OF SUB-COMMITTEE ON TOOL STEEL

IN the September, 1923, issue of TRANSACTIONS there appeared the first report of the sub-committee on tool steel, covering their activity during the year 1922-23. This report covered the recommended practice for the heat treatment of plain carbon tool steel and 18 per cent tungsten high speed steel. These two reports have also been published in the A. S. S. T. Handbook, September, 1923.

The present committee membership is composed of four users and three manufacturers; users: W. J. Merten, chairman, M. E. McDonnell, C. I. Neidringhaus and W. H. Phillips; manufacturers: J. A. Succop, C. M. Johnson and J. Trautman, Jr.

The activity of this committee was formerly under the direction of the Standards Committee of the A. S. S. T., but in October, 1923, the name of the Standards Committee was changed to that of the Recommended Practice Committee. In January, 1924, the Recommended Practice Committee assigned the sub-committee on tool steel, the work of preparing recommended practices for the heat treatment of non-shrinking tool steel and fast finishing steel. The committee has completed this work, and is now reporting its progress. The reports which follow, are tentative recommended practices, and will remain so until such time as they

are adopted as standards through letter ballot of the membership of the Society.

Recommended Practice for the Heat Treatment of Non-Shrinking, Non-Deforming, Oil-Hardening Tool Steels

General

THIS recommended practice covers the process to be followed in the heat treatment of so-called non-deforming, oil-hardening steels. There are steels of other analyses used as non-deforming steels, but they require different heat treatment temperatures, and, therefore, this recommended practice does not apply to them.

Chemical Properties

Approximate Chemical Analysis

Carbon	1.00 per cent
Manganese	1.00 to 1.25 per cent
Chromium	0.50 per cent
Tungsten	0.50 per cent

Annealing of Steel After Forging and Before Machining

Heating—Place steel in furnace so as to expose maximum surface area. Heat slowly and uniformly to a temperature of approximately 1475 degrees Fahr., (800 degrees Cent.,) and hold at this temperature for a sufficient time to obtain complete penetration of heat and complete refinement of grain.

Cooling—Cool in furnace, infusorial earth, mica, lime, or any medium that will permit of uniform, slow cooling.

Heat Treating of Non-Shrinking Tool Steel

Operations

Heating for quenching
Quenching
Tempering

Heating for Quenching—Heat the steel very slowly but uniformly to a dark red heat of approximately 1200 degrees Fahr., (650 degrees Cent.,) then raise temperature more rapidly but uni-

formly to the quenching heat of 1450 to 1500 degrees Fahr., (788 to 815 degrees Cent.,) and hold for complete penetration of heat.

Quenching—Quench from this temperature in light oil but do not cool below temperature of boiling water, 212 degrees Fahr., (100 degrees Cent.).

Tempering—Reheat immediately in oil or other heating medium at a temperature of 325 to 400 degrees Fahr., hold for one-half hour and quench from this tempering heat into hot water. For intricate or small sections quench in oil or air.

Notes About the Process

Non-shrinking steels are essentially oil-hardening steels. The ratio of bath volume to mass of steel is a very important factor and the heating up of the oil during prolonged and continuous quenching operation should be avoided.

Heating should be done very gradually and uniformly, preferably in a muffle furnace, the steel being out of contact with flame and furnace combustion gases.

The absorption of heat or its diffusion through this steel seems to be very much slower than in ordinary carbon or alloy steels. Therefore, this steel should be heated more slowly and quenched less drastically.

Uses

Taps; reamers; broaches; blanking-, trimming-, punching-, forming- and threading-dies; master-tools and gages.

Recommended Practice for the Heat Treatment of Finishing Steel

General

THIS recommended practice covers the process to be followed in the heat treatment of so-called fast finishing steel, sometimes also referred to as semi-high speed steel. This steel is fast finishing in comparison to carbon tool steel, but is not to be confused with high speed steel.

Chemical Properties

There are various types of fast finishing steels manufactured and it is not recommended that this is the most suitable steel to use, but simply points out that the heat treatments recommended refer to steels of the following approximate chemical composition:

Approximate Chemical Analysis

Carbon	1.35 to 1.50 per cent
Tungsten	3.50 to 5.00 per cent
Chromium	0.50 to 1.00 per cent
Vanadium	0.20 to 0.30 per cent

Annealing of Steel After Forging and Before Machining

Heating—Place steel in furnace so as to expose maximum surface area. Heat slowly and uniformly to a temperature of approximately 1450 to 1525 degrees Fahr., (790 to 830 degrees Cent.,) and hold at this temperature for a sufficient time to obtain complete penetration of heat and complete refinement of grain. It is recommended that the steel be heated in a closed pipe or box containing a small amount of carbonaceous material, similar to regular tool steel practice.

Cooling—Cool in furnace.

Heat Treating of Fast Finishing Tool Steel

Operations

Heating for quenching
Quenching
Tempering

Heating for Quenching—Heat the steel uniformly to 1475 to 1525 degrees Fahr., (800 to 830 degrees Cent.,) and hold for complete penetration of heat.

Quenching—Quench from this temperature in water.

Tempering—Reheat immediately in oil or other heating medium at a temperature of 300 to 500 degrees Fahr., (150 to 260 degrees Cent.,) according to the use to which the steel is put. For intricate or small sections quench in oil or air.

MAGNETIC DETERMINATION OF THE ELASTIC STATE

By A. V. de Forest

Abstract

The relations between stress and certain magnetic properties are discussed in this paper. A method of alternating current magnetic measurements is described which gives a critical determination of the elastic limit.

The relation between elastic and fatigue properties is illustrated by means of the Jenkin model and the magnetic results interpreted from that point of view.

IN the year 1600 Gilbert,[1] the first great magnetician, published the results of an interesting experiment. It was known long before that iron, when held in a vertical position, acquired south polarity at the lower end and north polarity at the upper end. It was supposed that the longer the iron was kept in that position the more magnetic it would become. Gilbert, however, discovered that tapping the iron while it was held suspended enabled it to at once acquire the same magnetic properties as it would have reached after many years' exposure to the earth's magnetic field without intentional vibration, although there is some evidence that temperature variations have the same effect as slight mechanical vibration in causing magnetic induction in weak fields.

A variation of the above experiment forms the basis for the latest work on stress-magnetic relations. M. L. Fraichet, in a series of articles in *Revue de Metallurgie*,[2] describes a method of studying quantitatively the Gilbert experiment. He stresses a steel test piece in a testing machine at constant rate of elongation under the action of a magnetic field, either that of the earth, or one stronger, induced by a solenoid winding surrounding the specimen. A test coil of many turns also surrounds the specimen and is connected to a sensitive, short period galvanometer for indicating the rate of change in permeability due to the applied

[1]Paper by Gilbert, in *De Magnete*, 1600.
[2]Paper by L. Fraichet, in *Revue de Metallurgie*, January, 1924, August, 1923.

A paper presented before the Boston Convention of the Society, September, 1924. The author, A. V. de Forest, is research engineer with the American Chain Co., Bridgeport, Conn.

stress. The reading of the galvanometer is recorded by a spot of light traveling over photographic paper, which is moved at constant speed, and, therefore, proportionally to the rate of elongation.

The resulting diagram shows characteristic differences between steels of different physical properties, and thermal or mechanical treatment, but all are alike in demonstrating the great changes in permeability throughout the elastic and semi-elastic portions of the diagram, and the slight magnetic effect of the plastic deformation. (See Fig. 7.) In fact, the distinction known as the elastic limit may be more easily drawn between these two regions on a magnetic-strain than on a stress-strain diagram.

In order to place vividly in mind the mechanism by which a metal resists deformation, and the effects of stress on magnetic properties, the writer will briefly describe the ingenious fatigue model devised by Prof. Jenkin.[3] A simple form of the model shown in Fig. 1 consists of a group of 3 elements, each composed of a rod fastened solidly at one end to a common head, on which slide, with an adjustable amount of solid friction, the blocks C severally attached through the medium of springs to the common head B, which slides freely on the rods. The model is operated by supposing block A and B pulled apart or pushed together by the crosshead and table of a testing machine. The requirements are stated by Prof. Jenkin as:

1. That it shall be elastic up to a certain point and then slip with solid friction.
2. That all the units shall not slip at once as the load on the model is increased.

It is, of course, recognized that the model only holds as an analogy up to the yield point. In fact, the model is not intended to demonstrate such phenomena as elastic hysteresis or elastic recovery after overstrain.

By setting the model with different amounts of friction on the several sliding blocks C of the different elements and different initial tension or compression in the springs, analogies are found to the behavior under stress of various kinds of steel. To illustrate the stress-strain relation, the blocks A and B are assumed to be pulled away from each other in a testing machine to simulate

[3]Paper by C. F. Jenkin, in *The Engineer*, December 8, 1922, page 612.

tension, and are brought nearer together to give compression results. Let us set the sliding blocks to give equal friction on the rods, and set the center C block to have initial tension in its spring, while the outer C blocks each carry half that quantity of initial compression in their springs. When the model is put in tension

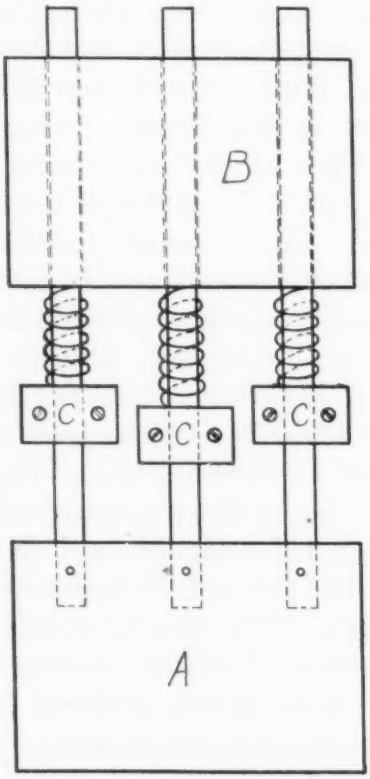

Fig. 1—Diagram of a Simple Form of the Jenkin Fatigue Machine.

the load is all taken by the springs up to the point of first slip, which will take place on the center block. This first slip takes place at the primitive elastic limit. The center block now carries no further increase in load, but slips as further deformation is applied; finally the end blocks begin to slip, and the yield point is reached.

The model illustrates the mechanism of fatigue as well as the stress-strain relations. If a repeated load is applied, the following changes appear as the loads increase: First, all motions are elastic, and the blocks under the highest initial load do not slip. There would then be no permanent cumulative change, and the load is

within both the elastic and the fatigue limits. With more load, the block having the highest initial stress in its spring will slip to a new position of greater equilibrium. By this is meant that if the load is varying between equal values of tension and compression and if the spring has a large initial tension, when the external tension load plus the internal load on that spring reach the point at which slip begins, the block will move to a point which increases its elastic range in tension and decreases it in compression. The motion of the block will then have shifted the elastic limit up to take care of the increased load. As the load is increased more and more blocks are slipped, initial stresses are literally shaken out, and the material becomes more and more elastic as far as the particular range of stress under consideration is concerned. A change in the stress range value, however, may mean that the slipping process must again be gone through with to reach new limits.

In terms of the model, the elastic limit is defined as the load which causes the first slip. The fatigue limit value is reached when cyclic loading causes no repeated slip. This condition is most easily reached by increasing the repeated load till slip has largely taken place, and then reducing the load to the point where no further slip occurs. In this condition the elastic range coincides with the fatigue range. This view of elastic and fatigue ranges illustrates the mechanism of raising elastic and fatigue limits by gradually increasing stress cycles, as shown by Gough[4] and Lea.[5]

Bauschinger's statement on the identity of elastic and fatigue ranges is then true in the special case where the elastic range has been raised by repeated loading. Evidently the cycle of stress in its relation to zero load determines the values in tension and compression of the new elastic limits. The elastic limit in tension for instance is as much a function of previous deformation as it is characteristic of the material tested. In order to have a stable base from which to measure, the material must be "de-stressed" and the fatigue limits be made equal on both sides of zero by repeated loading with equal tension and compression.

It is essential to bear in mind that the model does not indicate that repeated loading below the highest attainable value of the fatigue limit will cause failure. In actual material it seems that

[4]Paper by Gough and Hankins, in *Engineering*, May 12, 1922.
[5]Paper by F. C. Lea, in *Engineering*, February 23, 1923, page 252.

the newly established fatigue limits are slightly below the loading which causes the improvement. Change in properties of material due to a deformation or cold work, and the phenomena of elastic hysteresis are also not represented in the action of the model.

In the ordinary process of magnetization the relation between magnetizing force and induction is closely analagous to that between stress and strain. In a model representing magnetic action the same two requirements given by Prof. Jenkin might easily be invoked. The Ewing magnetic model in either its early simple form,[6] or in its later and rather complicated shape,[7] demonstrates all the effects of the combination slip and elastic effect through purely magnetic forces, replacing the slip component by the shift from one position of stable equilibrium to another. In fact, Ewing has presented a mechanical model of the stress-strain relations[8] which operates on the same basis as his magnetic model.

For the present, however, the Jenkin model may represent magnetic as well as mechanical phenomena. In the magnetic case the slip might be considered to occur very readily in some elements and not so readily in others. In this case the purely elastic range occurs at the lower values of magnetizing force. Under a particular application of magnetizing force a certain value of induction would be reached. However, upon the removal of this force the magnetic state of the material differs from its original condition. Hence at once it is apparent that in order to study the magnetic properties of iron and steel the previous magnetic history must be known, or the sample reduced to some arbitrary state of zero magnetization in order to have a suitable base from which to make measurements. If any piece of steel is picked up at random and the hysteresis diagram, (as the complete cyclic plot of induction versus magnetizing force is called), is drawn, it will be found that the first loop will be quite different from succeeding ones, each repetition of the loop approaching nearer and nearer to a definite form. In the terms of our model, it requires a number of alternations of stress to reach the state where all the blocks slip to the same extent for the same force, i. e., it takes a number of reversals before complete coordination is obtained. This point is labored in the attempt to show that no magnetic measurement

[6] "Magnetic Induction in Iron and Steel," by A. Ewing, in *Proceedings* of Royal Society, 1890, Vol. XIVIII, page 342.
[7] Paper by A. Ewing, in *Proceedings* of Royal Society, 1922, page 449.
[8] Paper by A. Ewing, Society for Advancement of Science (British), 1906.

is of much significance without a known base to start from, and that mere absence of external force is not enough to ensure that the effect of previous applications of force do not enter into what is supposed to be a measurement of a physical property characteristic of the material. It is exactly the same state of affairs which we saw existing in regard to the elastic limit; the previous load and, perhaps, the preceding stress cycles have an interposing effect. Absence of external stress does not ensure absence of internal stress, represented in the model by stress in the springs after the load is removed.

In case both stress and magnetizing force are acting at once it becomes evident from the Gilbert experiment that the magnetic properties are greatly affected.

The converse is likewise true, but to a much less extent. Direct evidence of the effect of cyclic magnetization on internal stress is shown by the following experiment: A piece of flat high-carbon steel is quenched so that one side is cooled more rapidly than the other. This results in warping and in high internal stress. If now the piece is measured and allowed to rest for a few days it will be found to have changed its curvature in a direction toward the relief of internal stress. Had the steel been cyclically magnetized it would have done the same at once; that is, changed shape in the direction of less internal stress. A slight shock, as a tap from a hammer or a slight bending back and forth, will have this same result.

A similar experiment consists in twisting to a permanent deformation a suspended wire which carries a mirror, so that a lamp and scale may be used to measure its return to normal. The slow creep caused by the relief of internal stress will take a sudden jump if the wire is given what may be called a magnetic shake-up, that is, a cyclic magnetization at high values of magnetizing force.

Less direct evidence may be deduced from the fact that any steel will change its apparent magnetic properties at low magnetizing force if given a "magnetic shake-up," and in hardened steel this causes a shift in magnetic properties in the same general direction as caused by a higher drawing temperature or a slower rate of quench. The existence of this shift in annealed steel is extremely interesting. It may indicate that internal stress is set up between grains as a result of the reorienting forces which cause grain growth. These forces may well be exceedingly pow-

erful, as indicated by the pressure exerted by ice crystals at the moment of their formation.

This aspect of the subject, namely, the study of stress changes caused by magnetic forces, has barely begun to receive attention, and the field is important both from the practical and theoretical viewpoint.

The change in magnetic properties caused by stress has received great attention at the hands of many investigators, particularly Ewing,[9] and Merica.[10] In general, the attempt has been made to study the effects of stress on magnetic properties using customary direct current methods, from the point of view of the physicist rather than that of the physical metallurgist.

We have seen that there is hysteresis, that is, a non-elastic relation between both mechanical stress and strain, and between magnetizing force and induction. It is, therefore, to be expected that there will be hysteresis between stress and induction at constant magnetizing force, and a relation which is very unstable and liable to sudden changes due, perhaps, to slight vibration. An inspection of the Fraichet curve, Fig. 7, shows that this is true. Other methods of direct current measurements show a similar result. A method of avoiding part at least of this disturbing effect of hysteresis is to use alternating magneto motive forces and in effect to keep up a small "magnetic shake-up" while making the magnetic measurements with the same force that does the shaking up. It is as though we were measuring the altitude of a balloon with an aneroid barometer which had the usual friction and back lash. To reduce these to a minimum we must tap the barometer before making a reading. A mechanism which keeps tapping the instrument will eliminate the apparent hysteresis between reading and altitude, which is in reality due only to friction in the measuring device. The same thing happens in direct current magnetic measurements. Hysteresis is greatly reduced; in fact, may be made to vanish under suitable conditions by a superposed alternating magnetic field.

The apparatus and method used in the magnetic examination of stress effects have been described in a previous paper[11],

[9] Same as Reference 6.

[10] "Ueber Beziehungen Zwischen den Mechanischen und den Magnetischen Eigenschaften einger Metalle bei Elastischen und Plastischen Formänderungen," by P. D. Merica. Friedrich-Wilhelms University, Berlin, 1914.

[11] "A New Method of Magnetic Inspection," in *Proceedings* of the American Society for Testing Materials, 1923.

and may here be briefly summed up as follows: An induction bridge is connected to a commercial 60 cycle lighting circuit and across the bridge is placed the moving coil of an alternating current galvanometer. The wiring diagram is illustrated in Fig. 2.

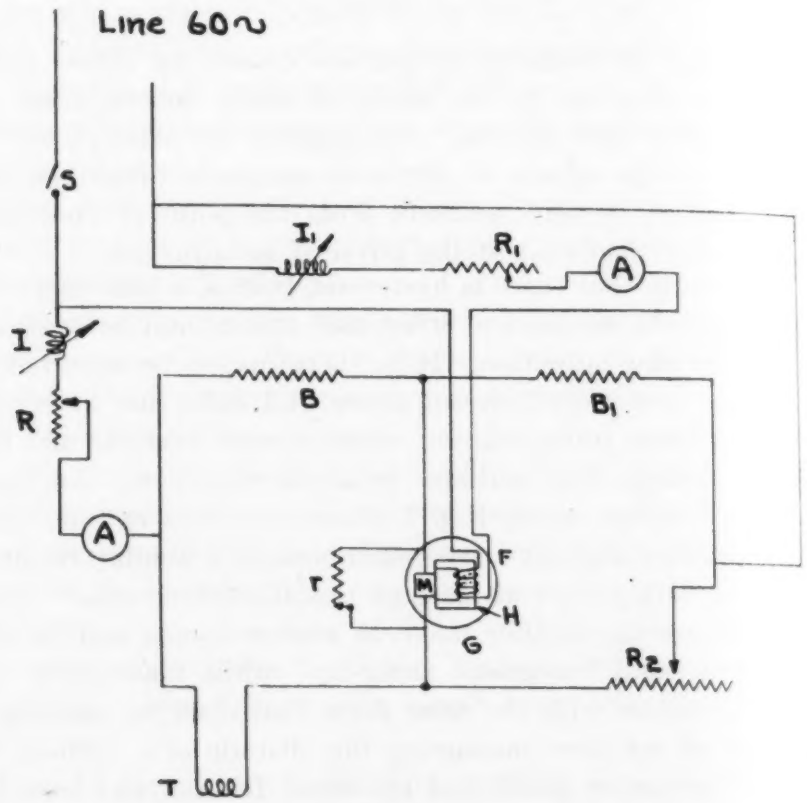

Fig. 2—Wiring of Induction Bridge Used in this Investigation.

Switch S controls the current for the whole apparatus. Variable inductances I and I_1, resistances R and R_1, and ammeters A and A, serve to regulate the current and adjust the phase relations in the bridge circuit and the galvanometer field H. A shunt resistance helps damp the moving coil M, of galvanometer G, which latter is bridged across between the ratio coils B and B_1 and the test coil T surrounding the specimen and the rheostat arm R_2. This latter may conveniently be made an inductance instead of the resistance shown. The galvanometer and control box are illustrated in Fig. 8. The moving coil system which is supported vertically by strained suspensions carries a mirror which deflects a spot of light focused on the under side of the record paper. Be-

tween the galvanometer mirror and the record paper the light is reflected from a plane mirror so mounted that it may be rotated around an axis at right angles to the motion of the galvanometer movement.

The ordinate of the position of the light spot is thus adjustable by rotating the plane mirror, while the absissa represents the

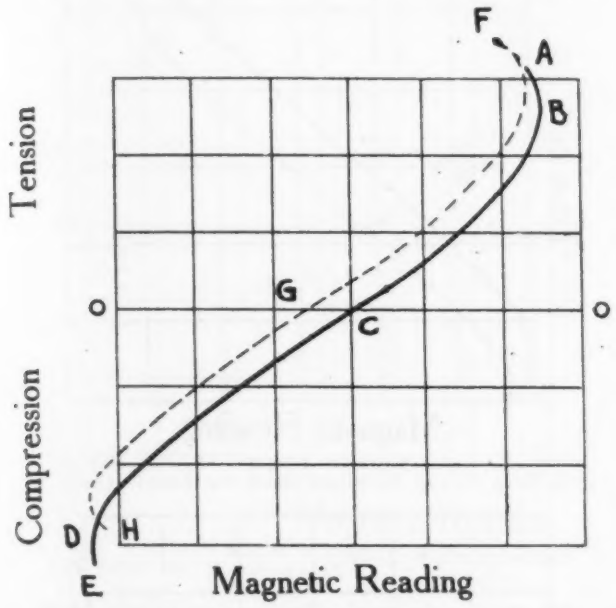

Fig. 3—Plot of Stress against Magnetic Reading Showing Effect of Slight Overstrain in Tension.

magnetic reading. In the case illustrated the load scale is laid out on the ruled record paper, so that to plot a reading, the spot of light is adjusted by means of the plane mirror, so that the ordinate indicates the load on the testing machine. The absissa gives the magnetic reading. The plot is made by recording with a pencil the successive positions of the spot as the stress is varied

The field of this galvanometer should be excited from the same circuit, and can most advantageously be connected in parallel with the bridge. The deflection of the galvanometer is now a function of the current flowing through it and of the time relation of the flux due to this current and that due to the field magnet. By means of capacity or induction in the bridge or field circuits the phase angle may be altered so that either the induction of the specimen may be measured, or if desired, the field flux may be adjusted out of phase with the flux due to the moving coil, and

the hysteresis and eddy current losses thus indicated. The effects of stress upon the quantities represented by these two measurements are different, and under proper conditions a certain value

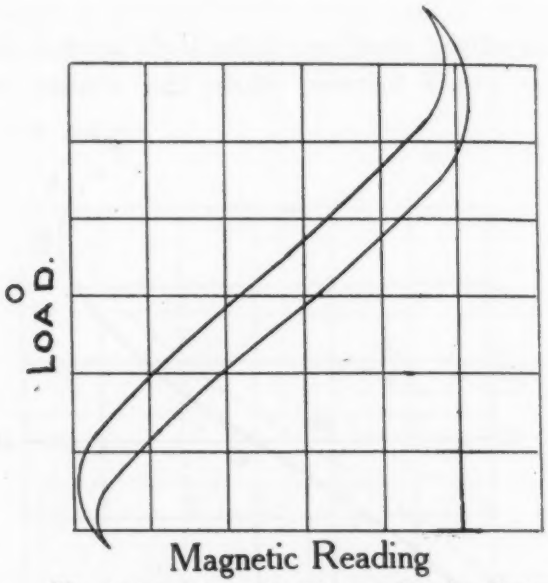

Fig. 4—Stress Magnetic Diagram Showing Hysteresis Loop Caused by Stress above the Elastic Limit.

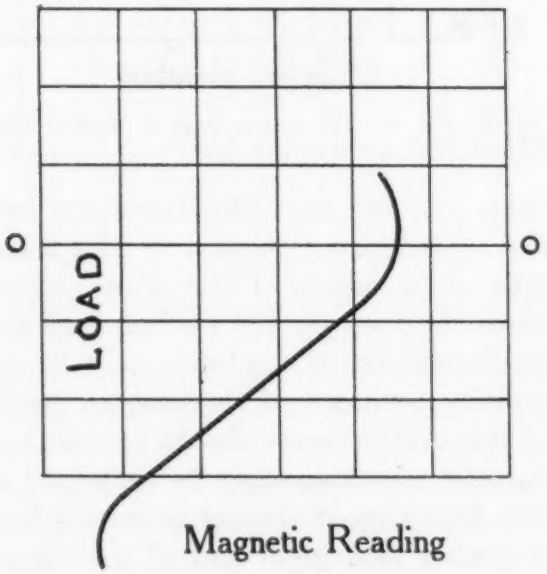

Fig. 5—Stress Magnetic Diagram Showing Elastic Range on the Compression Side of Zero Load.

of the phase relation between field and moving coil may be reached in which there is no apparent hysteresis between stress below the elastic limit and a magnetic measurement. As this is the simplest

possible case, let us see what light this measurement can shed on the mechanism of stress. In Fig. 3 stress is plotted as ordinate and magnetic induction as absissa at a suitable phase angle and magnetizing force. Starting from 0 load at C, the application of tension causes a deflection to the right following the curve of C B A.

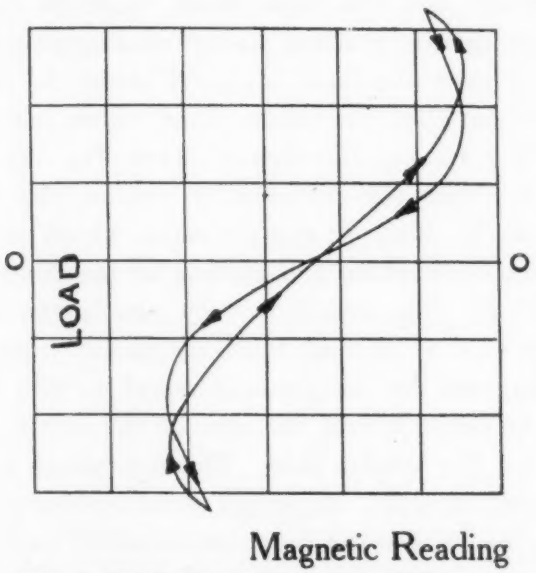

Fig. 6—Stress Magnetic Diagram Showing Hysteresis below the Elastic Limit.

Compression causes deflections to the left, C D E. The reversal of the curve at B is a peculiar feature of stress magnetic curves, and corresponds to the Villari reversal points.

This is properly the name of the point at which upon increasing the longitudinal magnetizing force upon a specimen of steel it ceases to lengthen and begins to shorten. The converse which we have here, namely, the point at which the magnetic measurement changes direction with increased load, may well be called by the same name, as it is undoubtedly another aspect of the same phenomena. This point varies with the material and the magnetizing force and has no direct relation to the elastic limit. The gradual departure of the line C B from the straight central portion of D C B is in no way to be confused with the significance of the departure from the straight elastic portion of a mechanical stress-strain curve.

In the picture of stress shown in the Jenkin model the elastic limit is reached when the load causes the first slip of one of the C blocks (Fig. 1). We have seen that the magnetic properties

are primarily related to stress or the deflection of the springs in the model. The small change of stress in the spring connected with the first block to slip is of small effect at full load in the presence of all the stress in the other springs, but after release, at 0 external load, its effect is a maximum, and due to the lowering of its own stress and the consequent shift in the stress of its neighbors the magnetic reading at 0 load shows a shift to the left of point C. If then the load is raised above A, the elastic limit, to F, where slight slip has taken place, upon release of load the magnetic reading follows the dotted curve FG. If this new curve is followed down into the compression region, the curve continues to H, a new elastic limit in compression, which shows a lowering of that limit approximating the raising of the limit on the tension side from A to F. The result is very nearly the same as though the whole curve A C E had been displaced toward the tension side of the diagram by an amount equal to the load above the elastic limit. In other words, the zero of the elastic range has been displaced toward the tension side. The zero stress line may thus be raised or lowered at will. Repeated stress cycles above the elastic range give results comparable to those obtained by Dalby[12] with his photographic stress-strain recorder, that is, a looped diagram is obtained, showing mechanical hysteresis and any progressive change. One loop is shown in Fig. 4. If the steel shown in Fig. 4 has not been stressed above a certain amount and is given a low temperature heat treatment, its elasticity is restored and the loop will shrink to a line, provided certain new elastic limits are not exceeded. Referred to the model, Fig. 1, this means that the heat treatment has, perhaps, changed the coefficient of friction between the sliding blocks and the rods.

The steel illustrated in Fig. 3 evidently had its 0 load midway between the tension and compression elastic limits. This is, strangely enough, not the general case. This specimen originally was made from cold rolled rod. The effect of the cold work was to give the diagram a greatly displaced 0, as in Fig. 5. All the elastic range is in compression. An anneal either above or below the critical points of the steel did not restore the zero to the center of the diagram, it only shortened the elastic range. Both in the annealed or cold-worked state the zero was brought to center by

[12] "Strength and Structure of Steel and Other Metals," by W. E. Dalby.

a gradually decreasing stress cycle of equal tension and compression exactly analogous to the demagnetizing cycles necessary to obtain a reproducible zero from which to make magnetic measurements. This stress cycle can most easily be approximated by rotating the specimen under a bending stress, as in the rotating beam type of fatigue machines. Some materials, as wire for ex-

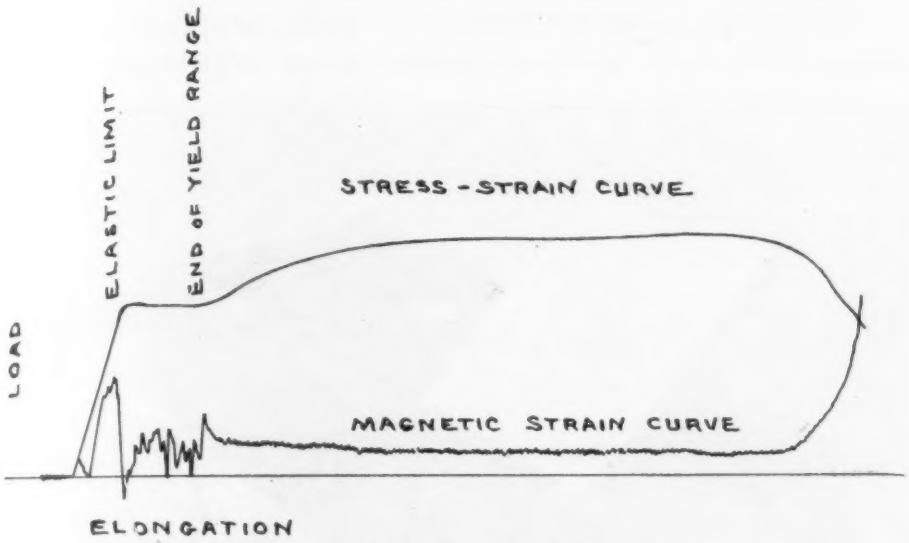

Fig. 7—Fraichet Diagram for Mild Steel.

ample, have elastic ranges designedly much greater in one direction than in the other. In this state of affairs a small reversed stress, such as caused by bending, may be vastly more destructive to the wire than a much higher tensile stress which, due to stress bias, the wire is able to withstand. A magnetic study of this case shows that the elastic range may be altered arbitrarily to conform to the requirements of a particular purpose. In many other cases, where stresses are limited in direction, the elastic range may be altered with that end in view. For instance, single acting engines could use connecting rods with the elastic range largely on the compressive side. Double acting engines need the range equally distributed.

In the Jenkin model, as we have seen, the elastic limit is the load at which the first slip takes place. The fatigue limit is reached when the load causes slip to reoccur at each cycle. The elastic limit is shifted up to the fatigue limit, which, from this point of view, coincides with the highest attainable elastic limit, by suitable

cycles of mechanical stress. Under normal conditions the fatigue limit, therefore, changes during the process of test. If we accept as a criterion of the elastic limit the highest load which does not cause a shift in a magnetic reading at 0 external load, we can easily follow changes in elastic behavior during tests and in actual service. While this is a possibility of great promise, it only touches the outside edges of the problem of fatigue.

The course of fatigue failure can be roughly divided into two parts, which may, however, overlap to an indeterminate extent.

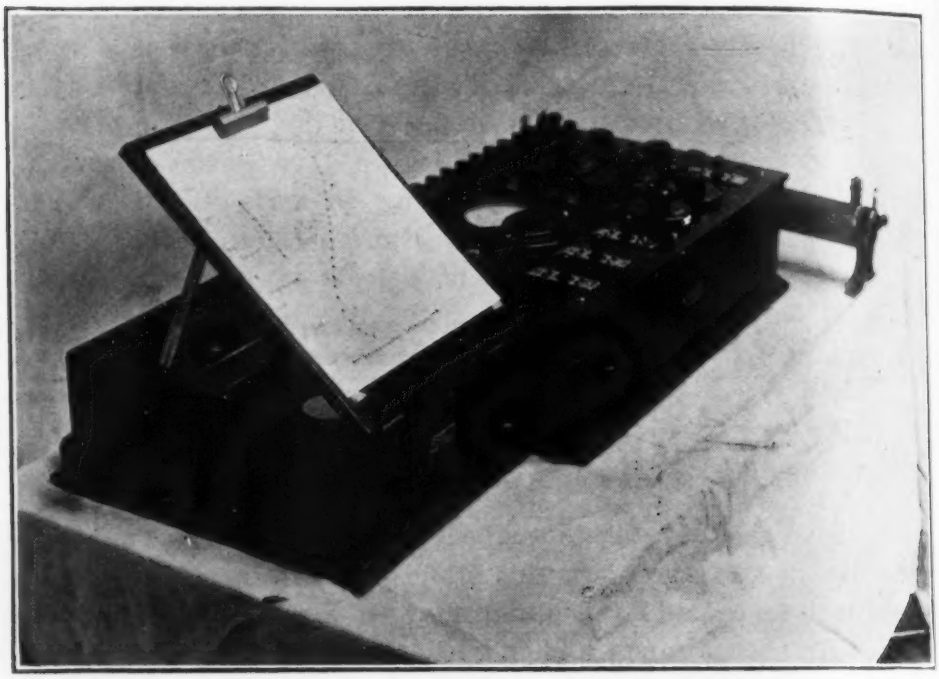

Fig. 8—Galvanometer and Control Box.

During the first stage slip occurs at a comparatively large number of places, so that the elastic and magnetic properties of the material as a whole are affected. This change involves the properties of a certain finite mass of material. Let us consider, for illustration, a test piece in alternating tension and compression of 0.10 square inch area and 0.5 inches long. A change in a magnetic property of 0.1 of 1 per cent would be easily recognized, in a volume of 0.05 cubic inches.

The second stage of a fatigue test comes when slip and deterioration extend what was at first the plane of least resistance into a slowly extending detail fracture. In the early part of this

process the volume of metal affected by fatigue might involve an area of 0.1 the cross section, or 0.01 square inch with a thickness almost infinitely small. Let us use a greatly exaggerated figure, say 0.0001 inch. The volume of metal involved in the change in properties is then 0.000001 cubic inch in a volume of 0.05 cubic inch, or 0.002 per cent of the volume under consideration. It is unreasonable to expect to measure directly a change involving such a small volume. Probably a smaller volume can be examined magnetically than in any other way except with a microscope, but the attempt to follow this second stage of fatigue failure remains difficult.

If a fatigue failure has begun it may be difficult to locate and measure. It is, therefore, important to study the first phase, and, if possible, to establish some relation between fatigue life and change in magnetic properties.

We have seen that the elasticity of a metal is by no means perfect. There is a mechanical hysteresis involved, probably the result of several different causes. Whatever these may be, it is probable that any cumulative change due to repeated stress would be reflected in a cumulative change of this elastic hysteresis, for it represents the dissipation of a certain quantity of energy at each cycle. Any increment of this energy, which is being used to disintegrate the metal, would be measured by an increasing change in the mechanical hysteresis. We have seen that the elastic properties and the magnetic properties are very closely connected, it is, therefore, to be expected that the hysteresis between stress and magnetic properties is related to the elastic hysteresis. This latter is a small quantity, and difficult to measure with exactness. Magnetic measurements involving hysteresis between stress and induction may easily and accurately be made.

A direct comparison between the changes in the two hysteresis loops, those of stress-strain and stress-magnetism, was not found possible, but a preliminary study of the change in the stress-magnetism loop showed that it was an easy matter to measure it with reasonable accuracy. As was expected, the area and width of the loop changed greatly with the previous mechanical history, widening on slight overstrain, and reverting when allowed to rest, or after heating. It appears from this that we are dealing with something akin to the elastic properties, and not a property which

varies permanently with fatigue life. This is what would be expected of the elastic properties.

These considerations are brought forward in the hope that others who are studying the subject of elasticity and fatigue may visualize the possibilities which lie behind the stress-magnetism relations. There is reason to believe that the useful strength developed by our strongest steel is far below the strength it would display if every fiber were equally resisting deformation. In fact our materials of construction frequently act as though a part of the section under stress has no opportunity of coming into play. Like a badly laid wire rope in which half the strands carry the whole load, our structures and machines carry enormous useless weight.

An attempt has been made to show how it may be possible to use stress-magnetic analysis in the study of this vitally important problem of elasticity, fatigue and unequal distribution of stress.

THE MICRO-STRUCTURE OF AUSTENITE AND MARTENSITE

By Francis F. Lucas

Abstract

In a previous paper the author disclosed the technique of photomicrography, by which remarkable resolution and depth of penetration could be obtained at high-powers. Subjects of academic interest were purposely selected for illustrations. The present paper applies the same methods to a study of the structure of austenite and martensite, from the results of which logical deductions of scientific value may be drawn. The results should be considered in the light of a progress report on some work under way in the Research Laboratories of the American Telephone and Telegraph Company and the Western Electric Company, Inc.

High-power metallography brings a new tool to the aid of the scientific worker in the field of metallurgical research. The uncharted gap bridging the finite as viewed by ordinary metallographic methods, and the elementary structure as revealed but not seen by methods of X-ray analysis, has been narrowed to a few hundred atom diameters. That the revelations by high-power photomicrography seem to corroborate the findings by methods of X-ray analysis is significant and should lead to a better understanding of metal structures.

FOR the purpose of studying the structural characteristics of austenite and martensite a special iron-carbon alloy was produced by combining carbon with Armco iron. By analysis, this alloy was found to have the following composition:

	Per Cent		Per Cent
Carbon	2.65	Sulphur	.015
Silicon	.01	Phosphorus	trace
Manganese	.07		

Acknowledgment is made to the Western Electric Company, Inc., for their courtesy in furnishing the half tone reproductions illustrating this paper.

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This alloy was hot rolled to a ⅜ inch rod. A section about four feet in length was heat treated in the following manner:

One end of the rod for a distance of about fourteen inches was placed in an electric furnace of the quartz tube type and the other end was allowed to project outside of the furnace, where it could be maintained approximately at atmospheric temperature. Both ends of the quartz tube were plugged so as to maintain the temperature within the furnace as uniformly as possible. The thermocouple was placed in close proximity to the central portion of the rod within the furnace.

The furnace was brought to 1,260 degrees Cent. (2,300 degrees Fahr.) and maintained at this temperature for a period of about five minutes, when the rod was quickly withdrawn and the heated end plunged into an ice and brine solution at a temperature of —10 degrees Cent. (14 degrees Fahr.). The quenching medium was stirred violently and during this operation a piece about seven inches in length broke from the heated end of the rod.

The heat treated end of the rod was divided for metallographic study in accordance with the plan shown in Fig. 1, and various specimens of convenient size to handle were numbered and lettered to agree with the diagram. The specimens numbered 25 lay between the break and the heated end of the rod and lettered from the heated end. Those numbered 26 lay between the break and the cold end of the rod and lettered from the break.

Specimen 25A was sectioned longitudinally and prepared with great care for microscopic examination. The center of the rod was found to consist of polyhedral grains of a solid solution containing acicular crystals of martensite. These polyhedral grains were surrounded by an intercrystalline eutectic and as the field under examination progressed from center toward the outside of the specimen the structure changed gradually from rather large polyhedral grains at the center, separated by an intercrystalline substance, to quite small grains at the outer part of the rod, and these were found to be arranged in a pattern, unmistakably dendritic. Hence the conclusion was reached that heating the alloy to this high temperature had caused the metal to revert to the original cast structure, but by rapid quenching the process had been arrested midway in the transformation. Figs. 2, 3 and 4 show the structure near the center; midway between center and

outside; and near the outside at a magnification of 175 X. The specimen in this case was etched with boiling sodium picrate.

Since boiling sodium picrate has the property of staining iron carbide, it becomes evident that specimen 25A is composed of a matrix rich in iron carbide and in which are disposed polyhedral grains of austenite. It will be noted that in the case of Figs. 2 and 3, at least, the polyhedral grains contain well defined acicular needles of martensite, which have responded to the sodium picrate test. The backgrounds of Figs. 2 and 3 are mottled, indicating that more than one constituent is present, but neither the magnification nor the resolution is sufficient to define the structure clearly. These pictures were taken with an apochromatic objective of best quality, but of low numerical aperture, and if objectives of high primary magnification and high numerical aperture were not available it is likely the details of this structure would have remained a mystery (Fig. 5).

Fig. 5 shows at high magnification the way in which an austenitic grain breaks up to form dendrites. The light background is iron-carbide and the small particles austenite. It will be noted that the small particles of austenite are arranged along straight lines marking a continuation of the crystallographic planes of the large austenitic grain.

Fig. 6 at a magnification of 2,400 X of specimen 25A, etched with picric acid, shows several small polyhedral grains, aligned with each other and having exactly the same orientation. The martensitic structure of one grain shows continuation in the adjoining grain. It is quite evident that a large austenitic grain has divided to form several smaller grains, and these in turn are shown dividing into smaller ones, by separation along crystallographic planes and by segregation and dissolution. It will be noted in some cases that the separated constituent is given off in very small particles, which have a martensitic structure.

Fig. 7 is of another field at a magnification of 2,400 X, in which a large austenitic grain is shown traversed by several groups of etching lines, suggestive of the nature of martensite, yet lacking the characteristic zig-zag needle-like structure of true martensite. Oftentimes both the cleavage or line structure illustrated in this photomicrograph and the true martensitic needles occur in the same grain.

Fig. 8 of specimen 25C at a magnification of 3,230 X shows

typical martensitic needles with points at the grain boundary. It has been observed that in the early stages of decomposition of austenite, the needles of martensite have a marked tendency to form from the austenitic grain boundary. In this picture, and in fact in all pictures, of martensite, the needle is seen to have a dark axis and oftentimes two or more needles are arranged, suggestive of twins. The modified form of austenitic decomposition, so pronounced in Fig. 7, also occurs in this illustration, and it also develops from the grain boundary.

Fig. 9 of the same specimen at a magnification of 3,230 X shows a broad martensitic needle of a rather granular appearance. This needle appears to be of twin formation because two distinct axes may be seen, and one of these is broad and dark. The selectivity for grain boundaries is also plainly to be seen insofar as the origin of martensite is concerned.

Fig. 10 of specimen 25C at a magnification of 5,600 X shows the structure of martensite to be somewhat granular. Origin at the grain boundary is apparent and the axes of the acicular crystals, which etch more darkly than the remainder of the crystals, are also evident.

Figs. 11 and 12 are of a small specimen of this same iron-carbon alloy, which was heated as described below. A specimen ¾ of an inch long was heated at 1,100 degrees Cent. (2,012 degrees Fahr.) and quenched in ice and brine at a temperature of —10 degrees Cent. (14 degrees Fahr.), after which it was sectioned longitudinally. The reason for this was to check the presence of troostite, which was found in several specimens of the 25 and 26 series, and which had developed directly from the austenite. These illustrations are at a magnification of 2,400 X and seem to show that austenite may convert to troostite without first having passed through the martensitic stage. In these illustrations well developed troostite is seen along the borders of the austenitic grains. The presence of the intercrystalline eutectic is apparent from Fig. 12. It will be seen that these austenitic grains contain acicular crystals, which are unmistakably martensite, and that the same grain may also contain the feathery cleavage line formations previously shown in Fig. 7.

Thus in a small specimen of a plain iron-carbon alloy it is possible, by suitable heat treatment, to retain austenite, martensite and troostite, and in addition an intercrystalline eutectic and a

feathery appearing constituent which, from what follows, appears to be of a structure similar to troostite.

Figs. 2, 3 and 4, referred to above, were taken with two objects in mind; 1. to show the development of the dendritic structure; 2. to show the constituents which respond to boiling sodium picrate and, hence, which may be assumed to be rich in iron carbide. This specimen (25A) was freshly prepared, the surface was ground on papers, so that all evidences of previous etching were removed. Following this the specimen was polished in the usual way and etched for 21 minutes in boiling sodium picrate.

Figs. 13 and 14 are of specimen 25C, etched for 20 minutes with boiling sodium picrate. Fig. 13 at a magnification of 1,800 X shows the austenite unstained and the martensite deeply stained. The axis of the martensitic needle is stained slightly darker than the rest of the needle. Troostite has developed near the grain boundary and is only faintly etched. The intercrystalline eutectic or dendritic mass is also to be noted. It is composed of a matrix deeply stained and contains unstained inclusions apparently of the same composition as the austenitic grain. The feathery cleavage line formation referred to above is now seen to have a black central vein which, when the specimen was etched with picric acid, remained white. The central black veins are bordered by a constituent which is only faintly stained and which, if studied carefully, will be seen to correspond almost identically in color and general appearances with the troostitic areas.

Fig. 14, also at a magnification of 1,800 X, shows the early development stages of a "fir tree" or dendrite from a polyhedral austenitic grain. Decomposition along parallel crystallographic planes has made inroads into the crystal, forming material rich in iron carbide. The intercrystalline eutectic, the martensitic needles, and small troostitic areas can be seen.

Fig. 15 is of this same specimen (25C) and shows at a magnification of 5,600 X the intercrystalline material. Details of structure are wholly lacking in the darkly stained portions, showing that this constituent is probably iron carbide. The inclusions which it contains presumably are saturated austenite, the particles often showing some decomposition.

In Fig. 7 a portion of an austenitic grain is shown in the process of dissolution to form the dendritic mass. It will be noted

that the grain has etched in such a way as to produce four sets of lines bearing a definite angular relationship to each other. In Fig. 16 of specimen 25A at a magnification of 2,400 X a grain is shown in which only two sets of lines are found and these are arranged at right angles to each other. In like manner other fields could be shown illustrating three sets of lines.

From a consideration of the work of Colonel Belaiew[1] and others on the crystallization of metals, these lines are known as the Widmanstätten structure and denote the inner symmetry of the crystalline matter, of which the grain is composed. Belaiew showed that the Widmanstätten structure in cast metals could be shown by deposits lodged parallel to the cleavage planes. He assumed four systems of lamellæ parallel to the four pairs of faces comprising the octahedron, and showed that two, three or four sets of lamellæ may be found on a section depending on the angular relationship of the cutting plane to the axes of the octahedron. For instance, if the section is parallel to the surface of a cube, only two sets of lamellæ will be found, or, if parallel to the surface of the octahedron or a dodecahedron, three sets of lamellæ; but any other cutting plane will result in four sets of lamellæ.

Thus it will be seen that in the austenitic grains illustrated the crystallographic planes of the metal have been revealed by a decomposition which has taken place along these planes and similar figures to those described by Belaiew have been produced. In the present case, the inner structure of the austenitic grain is seen not entirely by deposits of excess material lodged along crystallographic planes, but, also, by a decomposition which has occurred along these planes.

The exact nature of this decomposition product is open to some speculation, but a consideration of its metallographic characteristics throws some light on its nature. Picric acid is seen to etch rather deeply the feathery borders, leaving a central rib which is white (Fig. 7). Boiling sodium picrate stains the central rib black and only faintly so the feathery borders. In Fig. 13 it will be noted that the troostitic regions are stained almost identically as are the feathery borders, whereas the central rib is stained black the same as the intercrystalline matrix. From this we may conclude that the decomposed areas along these crystallographic

[1] "Crystallization of Metals," by N. T. Belaiew

planes are not identical with martensite, but are more nearly of the order of troostite, a carbide-rich constituent forming as a rib along the central axis. It seems probable that the decomposition is troostite, in which the excess constituent of carbide has formed along the crystallographic axis.

Fig. 17 of specimen 25C at a magnification of 2,100 X is of one of the austenitic grains containing a number of martensitic needles. These needles, at first thought, do not appear to bear a definite angular relationship to each other, but if studied closely it will be found that in general the arrangement follows an orderly plan, in which four sets of parallel lines exist, each line marking a plane parallel to the axis of a group of needles. If we liken the general shape of the martensitic needle to a feather, an analogy which seems quite appropriate, then it will be seen that certain of these needles are lying flat in a plane parallel to the surface of the section; others are on edge and are represented by narrow bands tapering toward their ends, so that obviously these needles have their minor axes in a plane at right angles to the surface of the section; still others are to be found which appear to be inclined at some angle other than approximately a right angle to the surface of the section. It also will be observed that the origin of the martensitic growth is either in the grain boundary, a feature of martensitic development referred to above, or one needle develops from another. From this we may conclude that martensite is a transformation developing along crystallographic planes in the form of acicular flakes or plates with tapering ends. These thin plates are marked by a central rib or major axis, which etches more deeply with picric acid than do other parts of the needle. When etched with boiling sodium picrate the major axes sometimes appear to stain more deeply, but the difference is less marked.

The development of martensite along crystallographic planes is illustrated by three diagrammatic sketches, in which the parallel sets of lines have been drawn to represent the various sets of cleavage planes which may be intercepted by a cutting plane dividing an octahedron. The central rib of the martensitic needle is almost invariably a straight line, and if the directions of these ribs as seen on a section composed partly of austenite and partly of martensite are plotted, figures similar to the line structure diagrams may be obtained. Fig. 18 is a section parallel to the sur-

face of a cube showing only two sets of lines. The martensite has the typical zig-zag arrangement, nevertheless it is traceable to the cleavage structure of the octahedron, in which only two sets of planes have been intercepted. Fig. 19 is similar to Fig. 18, except that the cutting plane is parallel to the face of an octahedron, in which three sets of planes are intercepted. Fig. 20 shows the condition found in most cases when the cutting plane is at random and four sets of planes are intercepted. This diagram was taken from Fig. 17.

If Fig. 17 is studied closely it will be noted that the martensitic needles show either a granular appearance already illustrated and referred to, or they appear to be traversed by numerous bands of parallel lines. One might infer that these lines were a result of the preparation work on the specimen, were it not for the fact that the austenite is almost wholly free of detail. Obviously any mechanical treatment which would scratch martensite would produce very deep scratches in austenite, however, this does not appear to be the case. This suggested that details of structure exist in martensite which, if they could be revealed, might throw some light on the nature of this constituent.

As martensite is etched more and more the surface of the needle becomes colored in shades of brown and red, and yields a mother-of-pearl appearance, typical of structures composed of fine lamellæ. Fig. 21 is an autochrome color plate taken by direct photography and illustrates this appearance. The magnification is 980 X. As the etching continues the needles become darker and darker, so that they reflect very little light, and thus become quite difficult to photograph. However, by concentrating attention on the martensitic needles and by using white light in place of the shorter wave-lengths for photography the writer found it possible to resolve the structure of these needles.

Fig. 22 is of specimen 25A at a magnification of 5,250 X. and shows quite clearly the lack of uniformity of structure of martensite and the development of three needles from a large needle. It should be noted that the three needles are parallel to each other, and in a measure substantiate what has been inferred that the development of martensite is along crystallographic planes. It also should be observed that the shading below the three needles extends only to the main axis or central rib of the large needle.

Fig. 23 is of another field at 5,250 X and shows the martensitic needle traversed by a number of parallel bands which etch to the same degree as the central axis of the needles. This plate was measured and the average thickness of these cross bands was found to be one-one hundred thousandth of an inch.

Fig. 24 at 5,250 X is of another field of this same specimen and shows a martensitic needle traversed by a large number of fine parallel lines arranged generally in two groups, which cross each other at a little less than a right angle. The average width of these lines was found to be about six-millionths of an inch. The central rib or major axis of this needle appears to have been etched away, leaving a deep furrow. Substantially the same characteristics are seen in Fig. 25, also of this same specimen, and at a magnification of 5,250 X.

Fig. 26 at 5,250 X shows quite clearly that the central rib of the martensitic needle etches very readily under the action of dilute picric acid, whereas the rest of the needle is only slightly attacked.

Figs. 27 and 28 represent diagrammatically the structure of martensitic crystals, as revealed by deep etching, and when examined at high powers. Less drastic etching often develops a granular appearance, but the lines can usually be seen, if somewhat faintly.

There is a micro-test for crystallinity of metals, and this is the phenomena of orientation displayed by revolving the stage of the microscope while the specimen is under observation. As the specimen revolves about the optical axis of the system, certain portions of it become light and dark by turns, as the light reflected from the tiny crystal facets falls within or without the aperture of the objective. In the case of an exceedingly fine substance, in which no orderly arrangement of matter exists, or in which the crystal facets are too small to be resolved by the objective, a general scattering of light should prevail and the specimen should remain uniformly illuminated, regardless of how the stage is turned. In the case of uniform crystalline arrangement, in which all of the metal within a given area has the same orientation, then the rays of light reflected from this area follow the same general direction and the specimen thus becomes light or dark by turns, depending on whether or not the rays reflected enter the objective as the stage is revolved.

A representative field was selected from specimen 25A, and the structure of martensite, when tested for crystallinity, failed to supply convincing evidence of a positive nature, although other constituents of hardened steel, such as a certain type of troostite, did respond when tested under the same conditions. Fig. 29 at 3,230 X is of the field selected for test and as the stage of the microscope was revolved the same tone of image persisted, i. e., bright areas remained bright and dark areas dark, or at least the change was not perceptible enough under the conditions to justify the definite conclusion that the metal is crystalline within the range of sensitivity of the test.

With the object of determining the crystal form of austenite specimen 25C was prepared with the usual degree of care and then etched for a long time with several different reagents, such as dilute nitric acid, hydrochloric acid, ammonium persulphate, aqua regia, etc. The specimen was examined at frequent intervals. Using this sort of treatment,[2] wrought iron and some alloys containing iron will develop perfect cubic or other crystal outlines, but in the case of austenite the metal etches very slowly, and there seems to be a tendency for the edges and corners of the figures to round off, so that the result is not sharp and distinct, as in the case of wrought iron. Moreover, the figures developed in wrought iron are much larger than those developed in austenite. Figs. 30 and 31 at 6,000 X are of areas of specimen 25C, which were wholly of austenite and show that the crystal form is unmistakably cubic. Of course, an octahedron may be sectioned in such a way as to result in a cubic figure, but it is inconceivable that all grains of a given specimen could possibly yield the same sort of figures because the probabilities are in favor of obtaining rhomboids or triangular-shaped figures, rather than squares. In a study[3] of the Carthage, Tenn., meteorite, composed roughly of 89.5 per cent iron and 7.7 per cent nickel, the writer was able to develop perfect sections of an octahedron, but seldom a section of a perfect cube. The evidence, therefore, seems to indicate that austenite crystallizes in the form of tiny cubes, but since it has been shown conclusively that the line or cleavage structure of the octahedron may also be produced in austenite, then it becomes

[2] "High-Power Photomicrography of Metallurgical Specimens," by F. F. Lucas, in TRANSACTIONS of the American Society for Steel Treating, November, 1923.

[3] "Photomicrography and Technical Microscopy," by F. F. Lucas, in the *Bell System Technical Journal*, January, 1924.

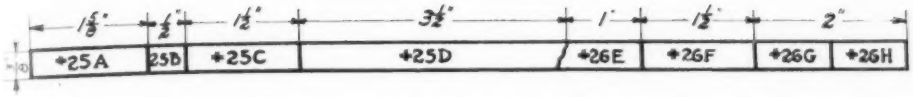


Fig. 1—Diagram of Rod Divided for Metallographic Examination

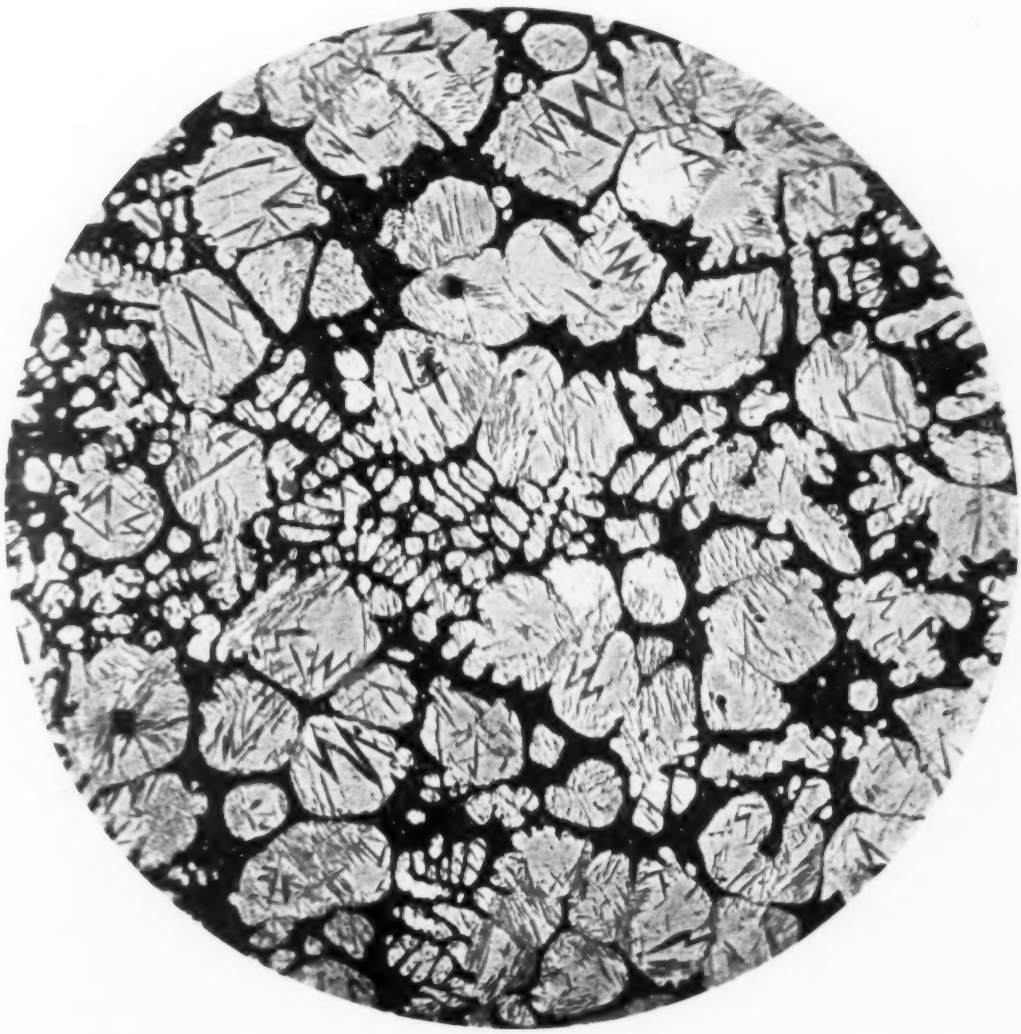


Fig. 2—Center of rod

The crystallographic relationship between the polyhedral and the dendritic forms of structure. The polyhedral grains (of austenite) break up along crystallographic planes forming the characteristic dendritic structure. Specimen 25-A etched with boiling sodium picrate—Magnification 175X

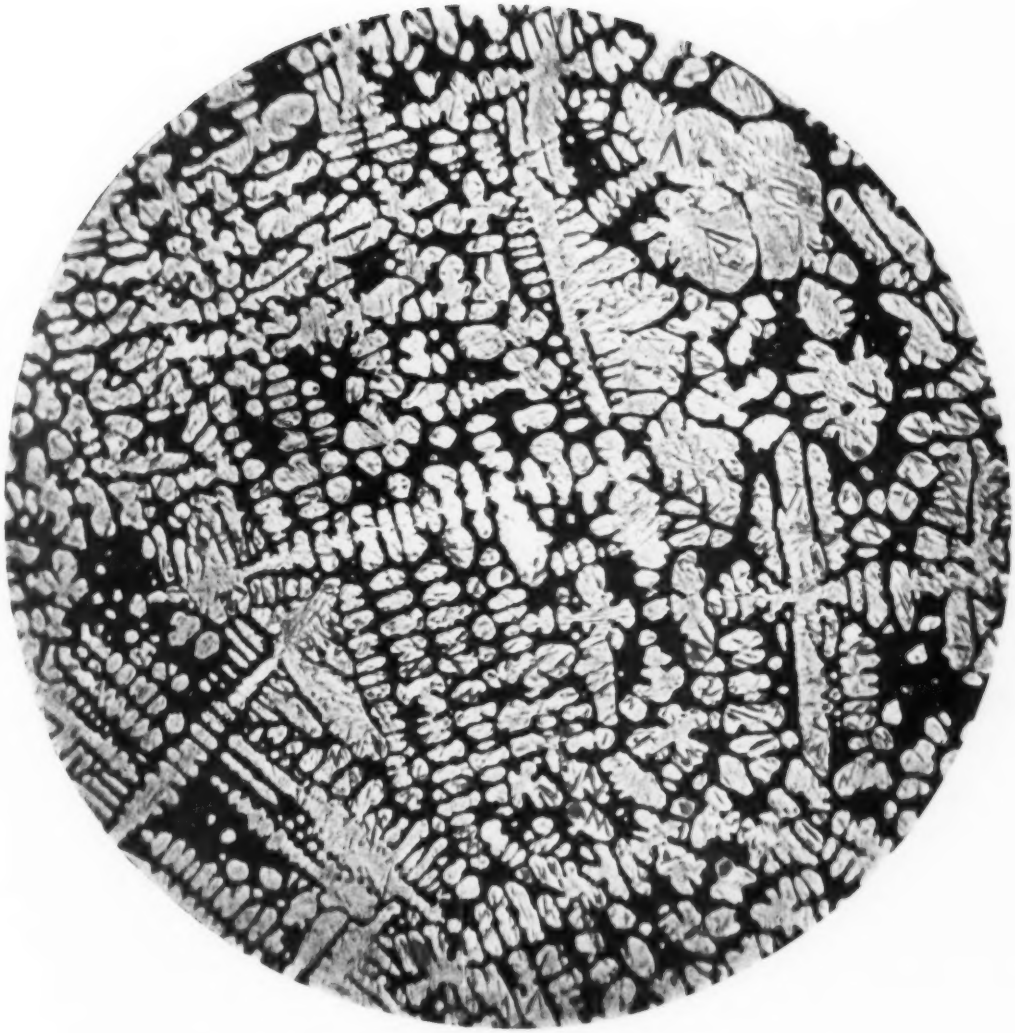


Fig. 3—Midway between center and outside of rod

The crystallographic relationship between the polyhedral and the dendritic forms of structure. The polyhedral grains (of austenite) break up along crystallographic planes forming the characteristic dendritic structure. Specimen 25-A etched with boiling sodium picrate—Magnification 175X

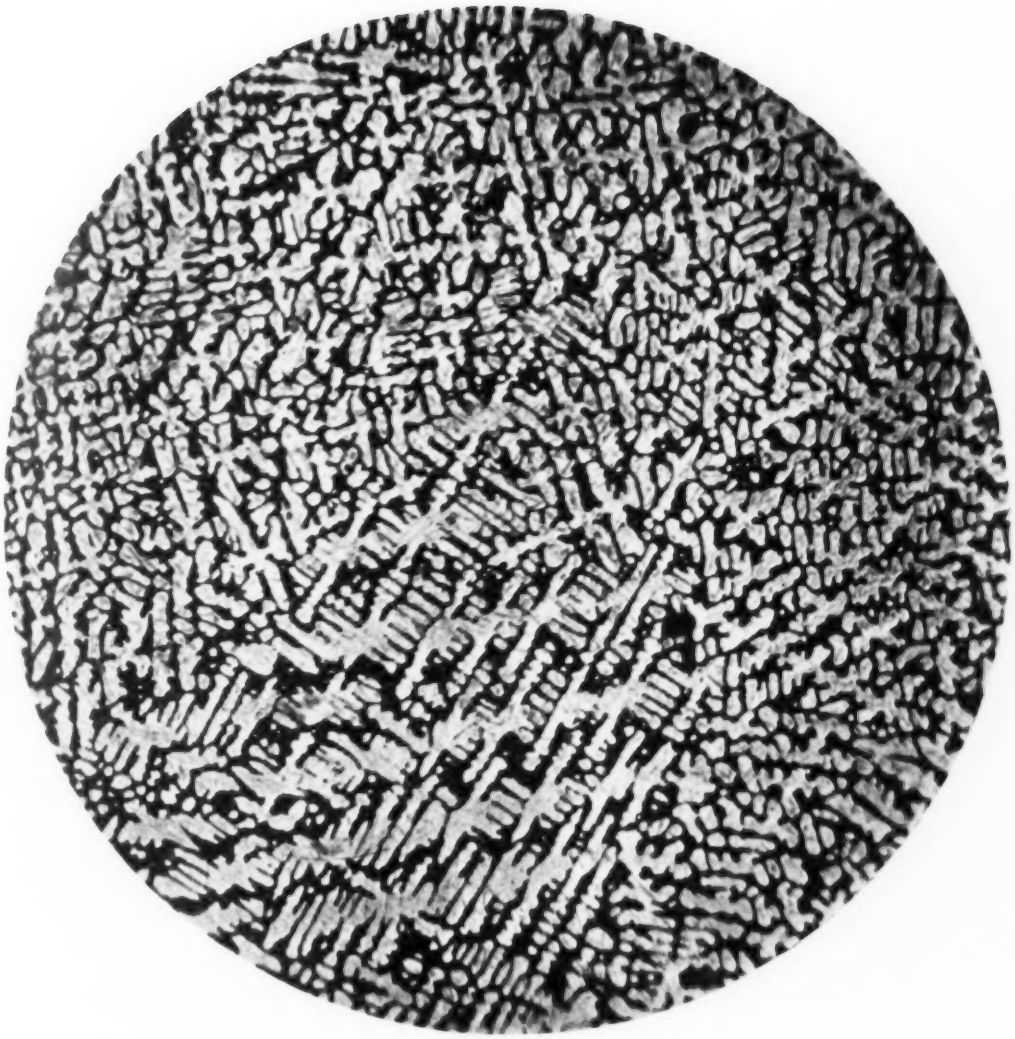


Fig. 4—Outside of rod

The crystallographic relationship between the polyhedral and the dendritic forms of structure. The polyhedral grains (of austenite) break up along crystallographic planes forming the characteristic dendritic structure. Specimen 25-A etched with boiling sodium picrate—Magnification 175X

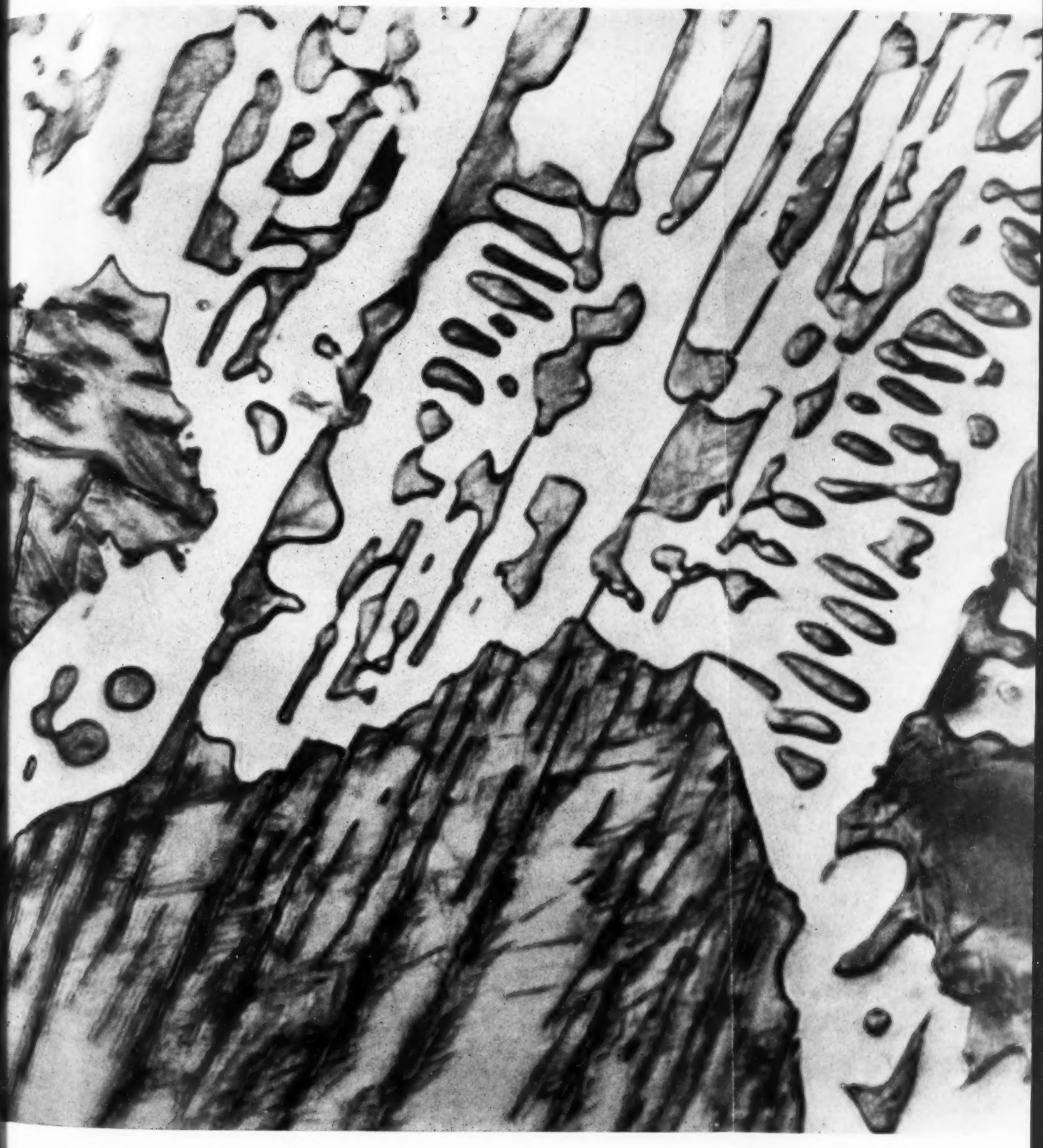


Fig. 5—Specimen 25-A etched with picric acid and showing the way in which an austenitic grain breaks up under suitable heat treatment forming dendrites. The light background is iron-carbide, the small particles saturated austenite—Magnification 5250X

Fig. 6—A large austenitic grain in the process of reverting to the dendritic structure. The same orientation persists in the separated grain particles which are arranged along crystallographic lines. Specimen 25-A etched with picric acid—Magnification 2400X

Fig. 7—Decomposition along crystallographic planes in a grain of austenite. In this case four sets of parallel lines have been developed. Specimen 25-A etched with picric acid—Magnification 2400X

Fig. 8—Development of martensitic needles at the grain boundary of austenite. Note the fine, granular structure of the martensite. Each needle has an axis or midrib, and these axes are arranged in parallel groups. The axes of adjoining needles meet at a common point. Specimen 25-A etched with picric acid—Magnification 3230X

Fig. 9—Showing the fine granular structure of martensite. Twin formation; and axis of needle more deeply etched than other parts. Specimen 25-A etched with picric acid—Magnification 3230X

Fig. 10—The finely granular structure of martensite. Specimen 25-A etched with picric acid—Magnification 5600X

Fig. 11—Nodular type troostite formed by the direct decomposition of austenite to troostite. Small specimen heated to 1100°C. and quenched in brine. Specimen etched with picric acid—Magnification 2400X

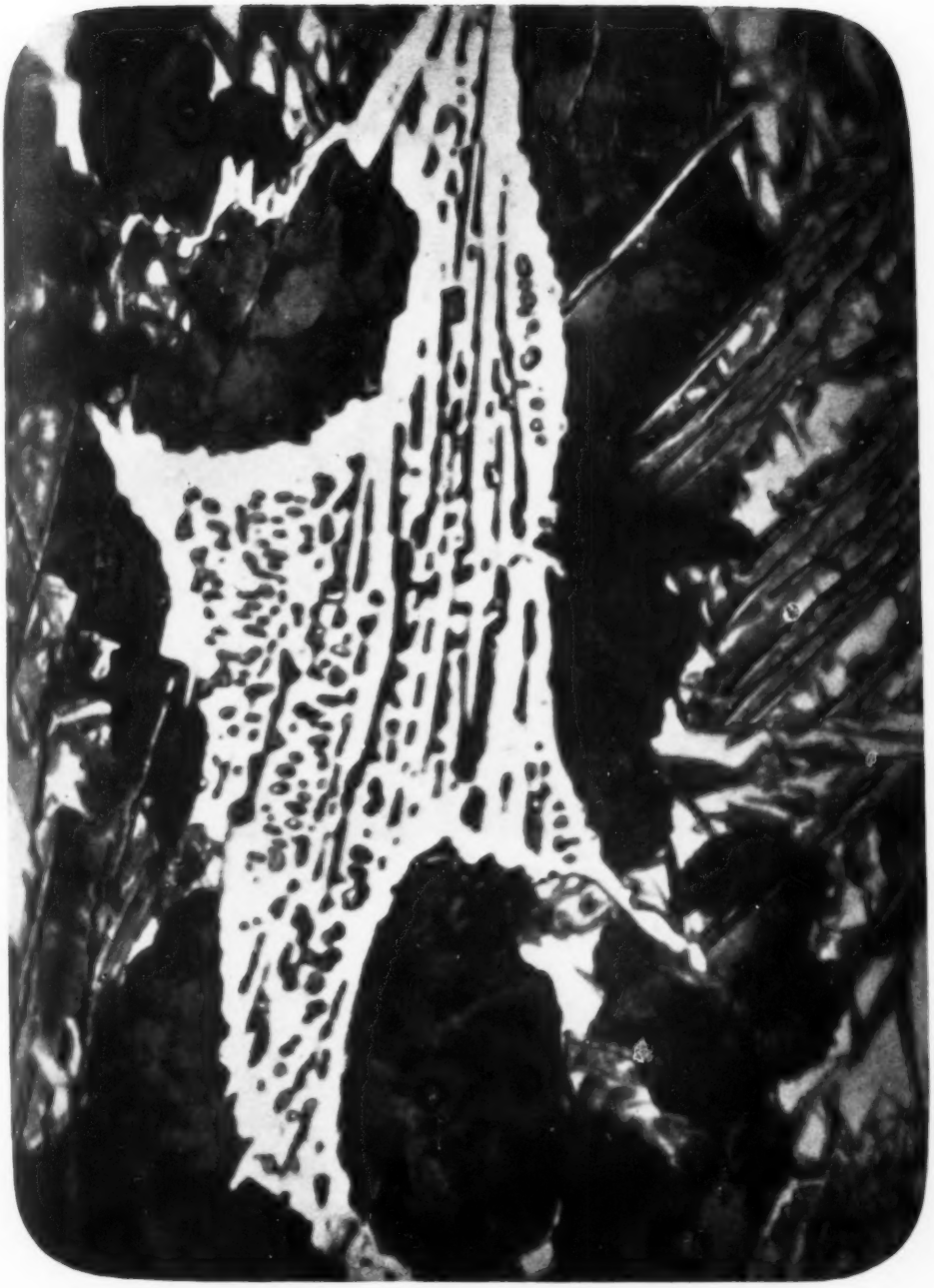


Fig. 12—Development of troostite along the boundary of the austenitic grain. Same specimen as Figure 11—Magnification 2400X

Fig. 13—Specimen 25-C etched with boiling sodium picrate

Austenite=	unstained
Martensite=	deeply stained
Troostite=	faintly stained
Intercrystalline matrix=	very deeply stained
Axes of "line structure"=	very deeply stained

Feather edge of "line structure"=stained same as troostite

Compare structural characteristics with those of Figures 11 and 12, when etched with picric acid—Magnification 1800X

Fig. 14—Early stages in the formation of a "fir tree" or dendrite from a polyhedral grain of austenite. Specimen 25-C etched with boiling sodium picrate

Austenite=	unstained
Martensite=	deeply stained
Troostite=	faintly stained
Intercrystalline matrix=	very deeply stained
Axes of "line structure"=	very deeply stained
Feather edge of "line structure"=	stained same as troostite

Compare structural characteristics with those of Figures 11 and 12, when etched with picric acid—Magnification 1800X

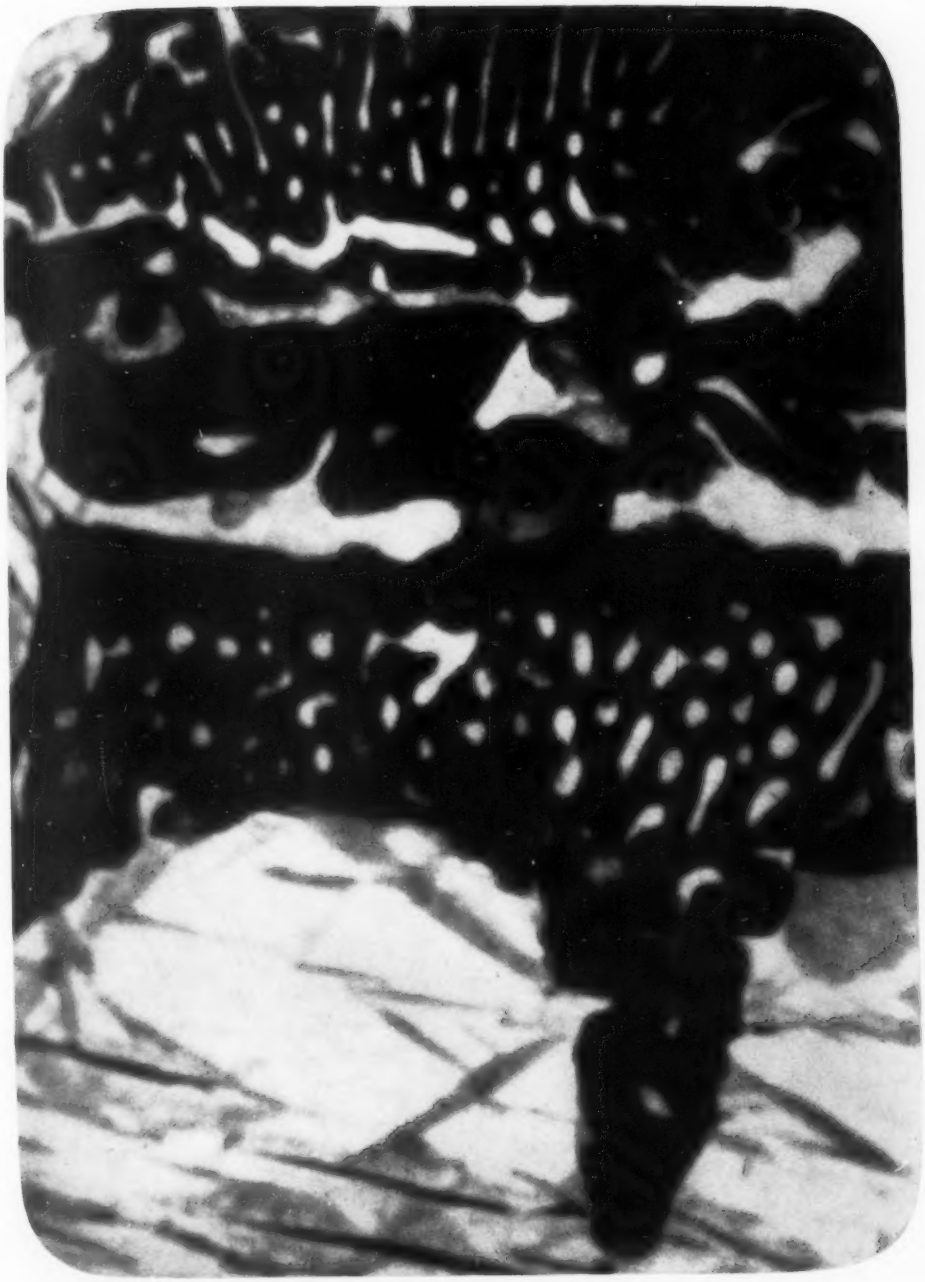


Fig. 15—Specimen 25-C etched with boiling sodium picrate showing the intercrystalline eutectic composed of a black matrix, iron carbide, containing particles of an unstained constituent, austenite—
Magnification 5600X

Fig. 16—Figure 7 shows four sets of lines developed in the austenitic grain. This photomicrograph shows two sets of lines and thus the section is parallel to the surface of a cube. In like manner, the development of three sets of lines can be shown. The development of the line or Widmanstätten structure traces the crystallographic planes of austenite to the regular system, octahedral form. Specimen 25-A etched with picric acid—Magnification 2400X

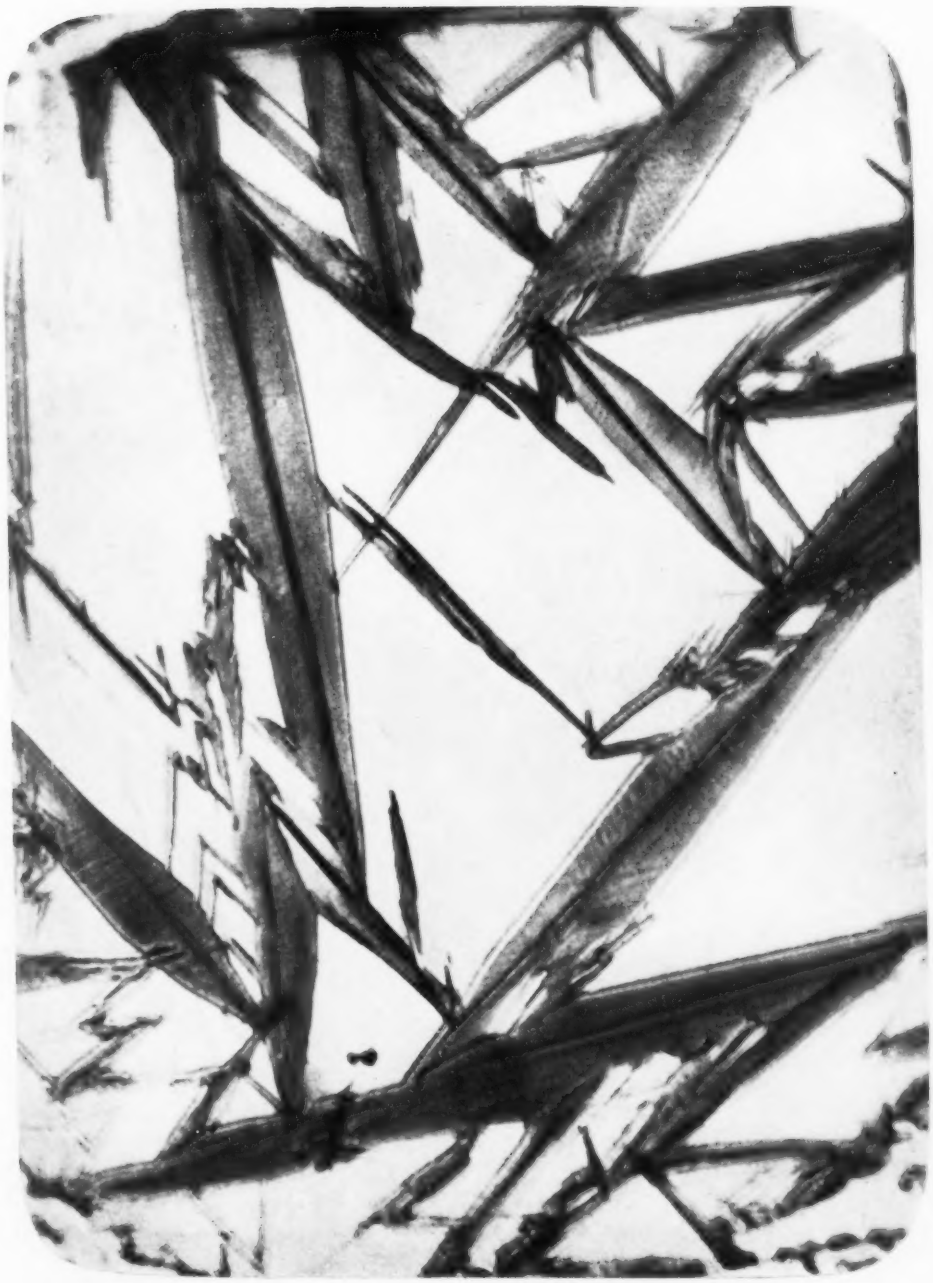


Fig. 17—Martensite in austenite. If lines are drawn parallel to the axes of the needles, four sets of parallel lines will result. If the needles are likened to feathers, it will be noted that some are lying flat, others are on edge and some are intermediate in position. Martensite is probably a decomposition in the form of thin flakes or plates parallel to the crystallographic planes of austenite. Note the striated appearance of the needles and compare with Figures 22, 23, 24, 25. Specimen 25-C etched with picric acid—Magnification 2100X

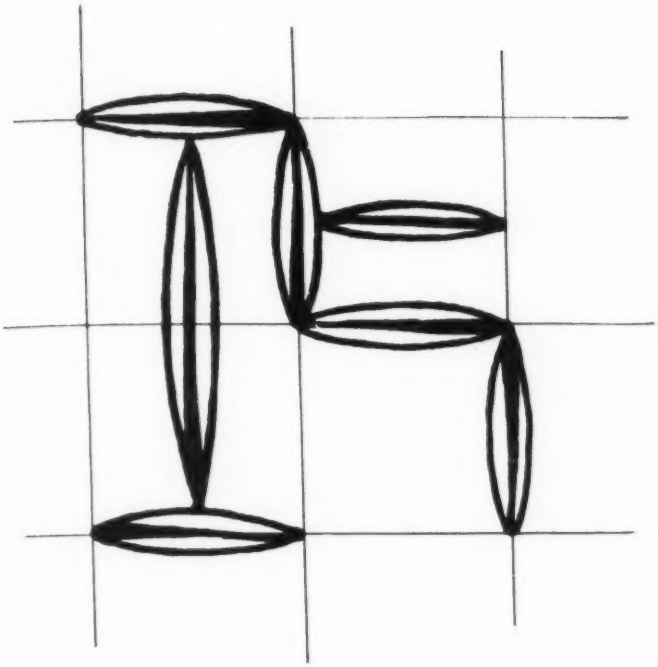


Fig. 18—Development of Martensite Along Cleavage Planes Parallel to the Surface of a Cube—Two Sets of Planes

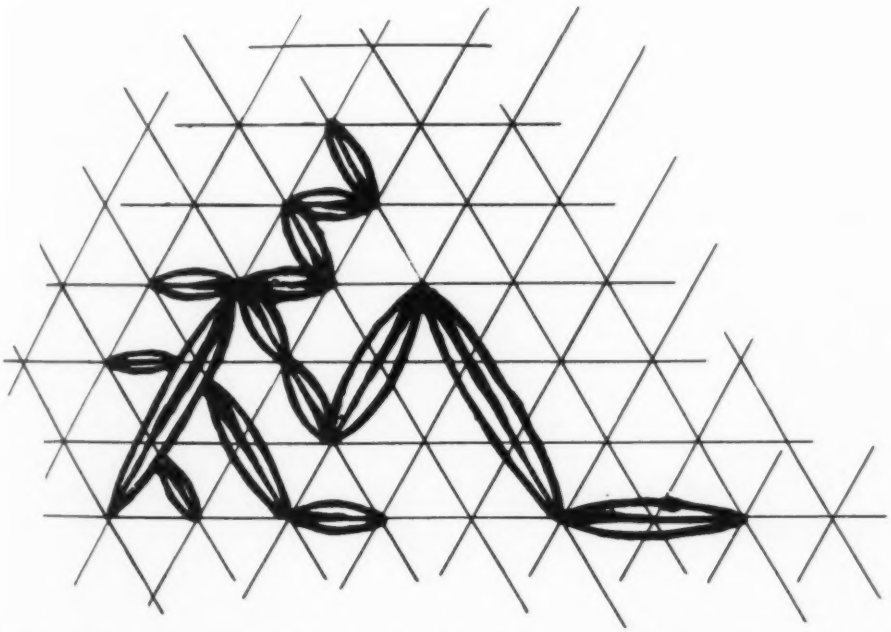


Fig. 19—Development of Martensite Along Cleavage Planes Parallel to the Surface of an Octahedron—Three Sets of Planes

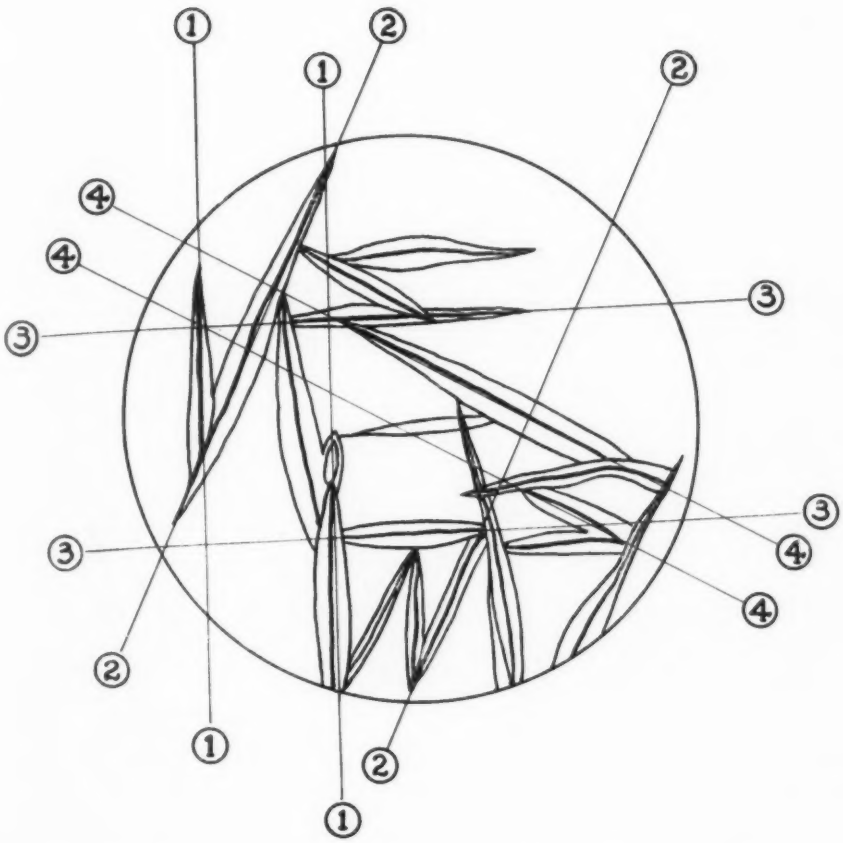


Fig. 20—Development of Martensite Along Cleavage Planes
Four Sets of Planes—From Figure 17

Fig. 21—Specimen 25-C etched with picric acid and photographed by a direct-color process. Mother-of-Pearl colors are shown in martensite—Magnification 980X

Fig. 22—Development of four parallel needles from a large needle. The axes of the developing needles appear to have their origin in the parent needle (note shading). The surface of the parent needle is quite mottled which seems to indicate that more than one constituent is present. Specimen 25-A deeply etched with picric acid—Magnification 5250X

Fig. 23—The parallel dark bands crossing the martensitic needles appear to be multiple twinning such as frequently is found in rock sections. The average width of the twinned bands is of the order 1/100,000 inch. Specimen 25-A deeply etched with picric acid—Magnification 5250X

Fig. 24—The mother-of-pearl appearance of properly prepared martensite when seen visually at high-powers appears due to a fine lamellar structure. Measurements show the lamellae in these photomicrographs to be of the order 6/1,000,000 inch in thickness. Specimen 25-A deeply etched with picric acid—Magnification 5250X

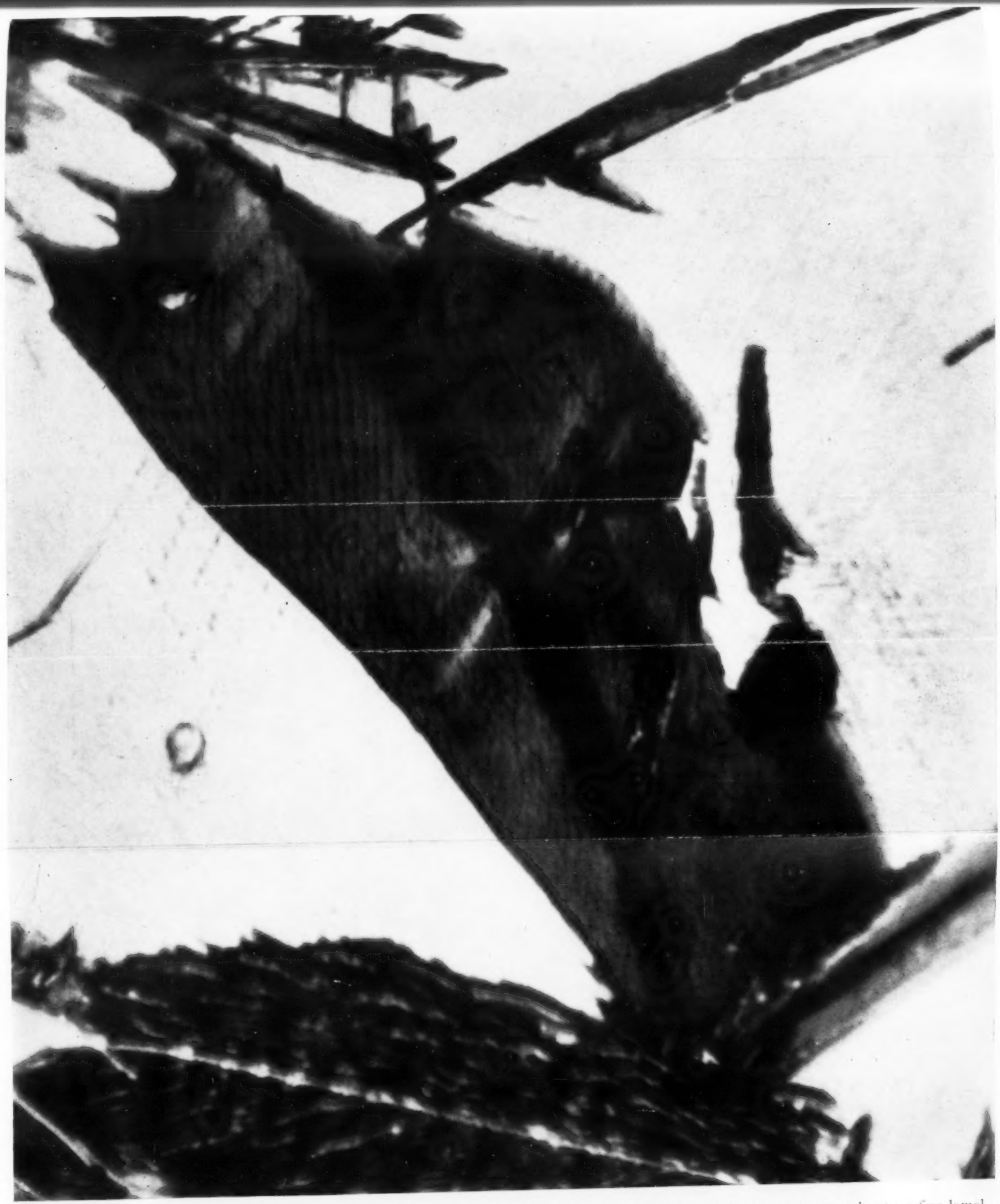


Fig. 25—The mother-of-pearl appearance of properly prepared martensite when seen visually at high-powers appears due to a fine lamellar structure. Measurements show the lamellae in these photomicrographs to be of the order 6/1,000,000 inch in thickness. Specimen 25-A deeply etched with picric acid—Magnification 5250X

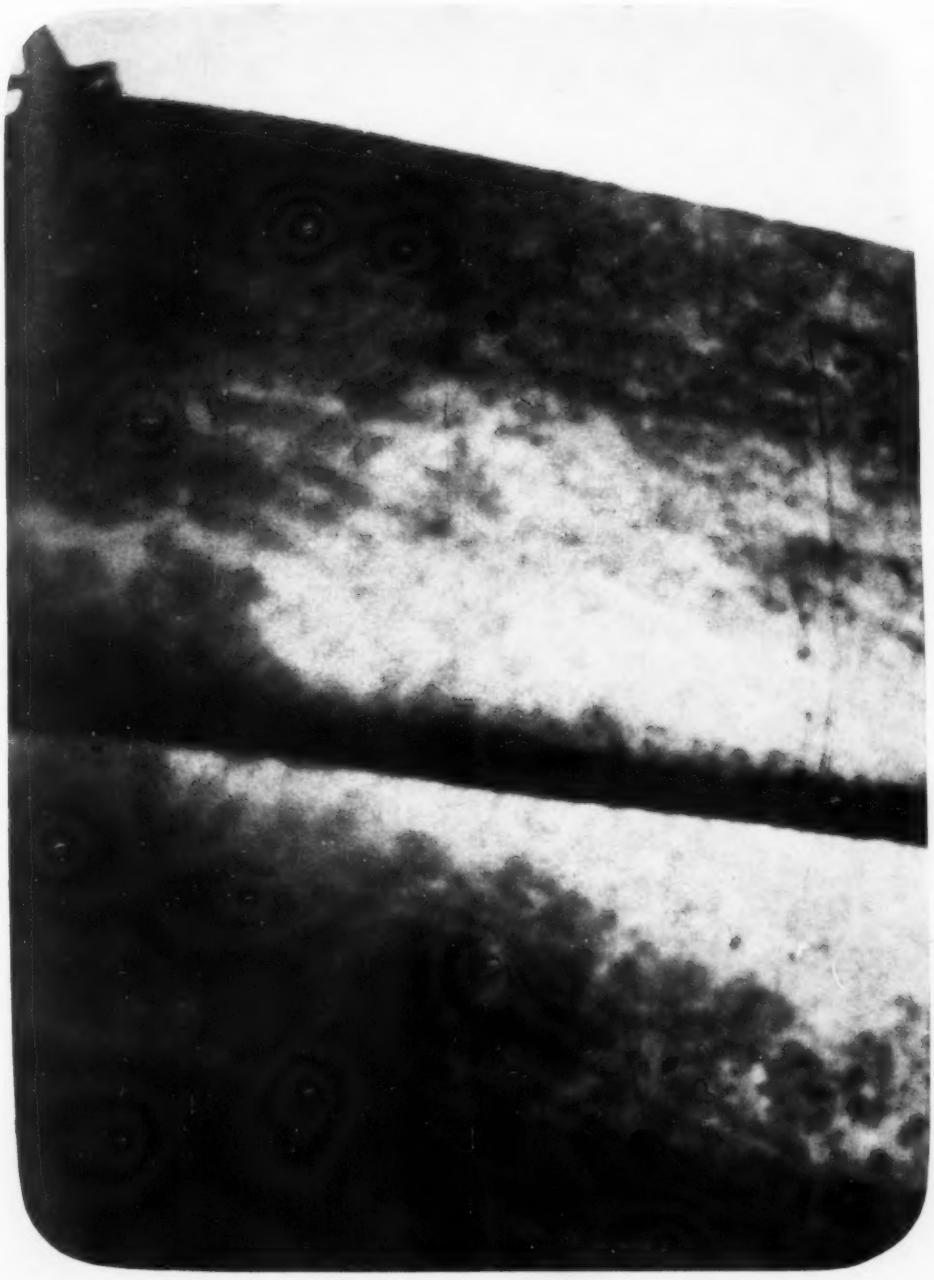


Fig. 26—Portion of the surface of a martensitic needle at high-power. Note the mottled appearance and the "line structure" faintly developed. Axis etched more deeply than rest of the needle. Specimen 25-A rather lightly etched with picric acid—Magnification 5250X

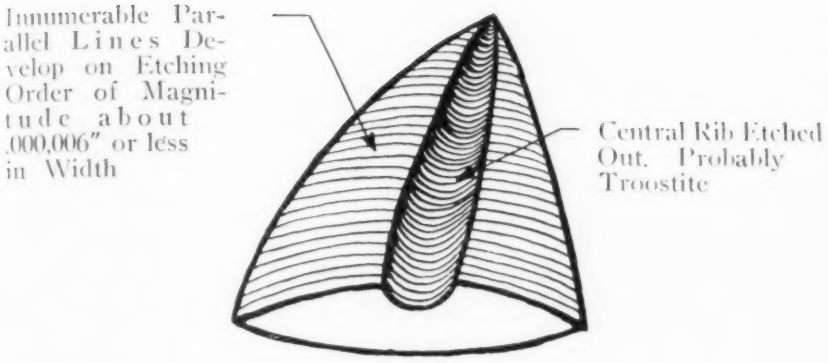

Immumerable Parallel Lines Develop on Etching Order of Magnitude about .000,006" or less in Width
Central Rib Etched Out. Probably Troostite

Fig. 27—Diagram Illustrating Probable Structural Arrangement of a Martensitic Needle With Fine "Line Structure"

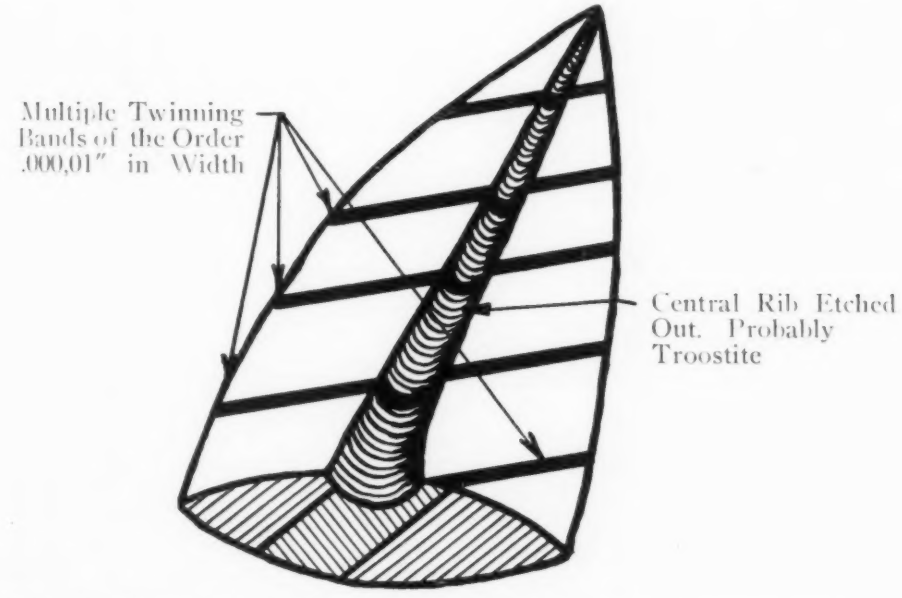
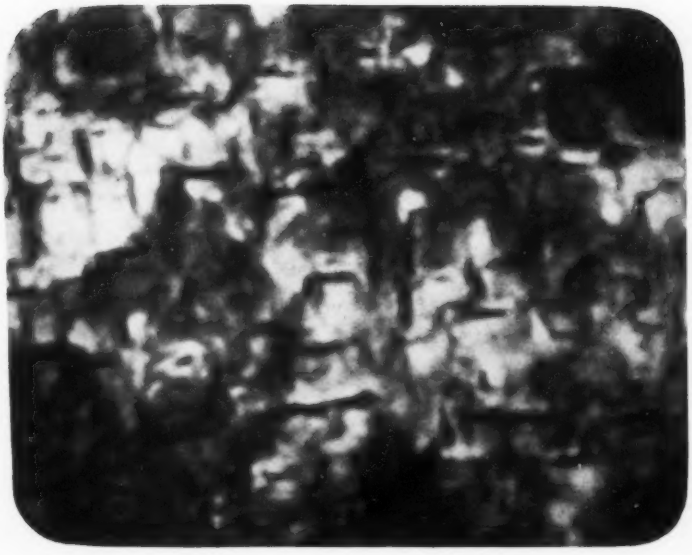
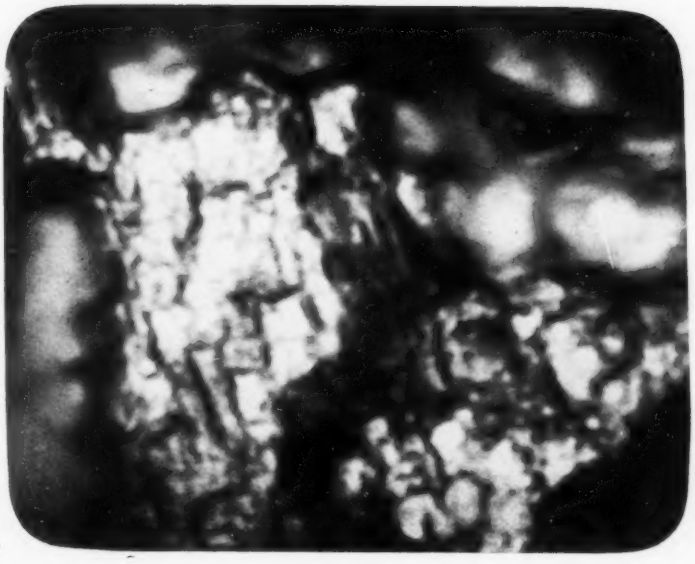


Fig. 28—Diagram Illustrating Probable Structural Arrangement of a Martensitic Needle With Multiple Twinning

Fig. 29—Specimen 25-A more severely etched than shown in Figure 26. "Line structure" well developed and main axes etched deeply forming grooves. Note the small cubic pits developed in austenite and compare with Figures 33 and 34—Magnification 3230X





Figs. 30 and 31—Specimen 25-A etched for a long period of time and in such a way as to develop the crystal structure of austenite. Very small cubic figures are invariably developed from which it appears that austenite is composed of cubic crystal forms—Magnification 6000X

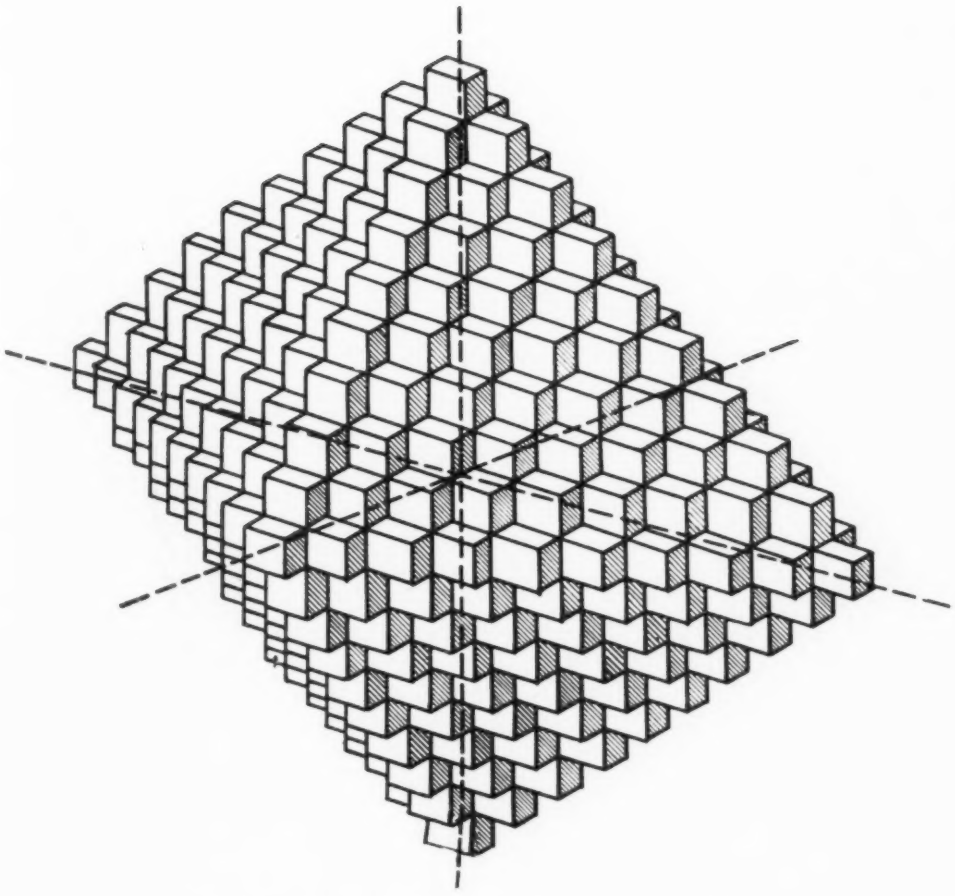


Fig. 32—Octahedron Built Up of Cubes (After H. M. Howe)

Fig. 33—The appearance of tiny cubic pits in Figure 29 suggested that some transformation had probably preceded the formation of martensite or progressed with it. By careful manipulation, it was found possible to develop this characteristic where heretofore it had remained obscured. The cubic figures are of the order 1/100,000 inch to the side and probably are ferrite. Some tempering action appears to favor their development. Specimen 25-A etched with picric acid—Magnification 3230X

Fig. 34—Another field of the same preparation from which Figure 33 was taken—Magnification 3230X

Fig. 35—Specimen 25-A etched with boiling sodium picrate and in such a way as to develop the cubic figures. The figures are not stained by the etching reagent—Magnification 3230X

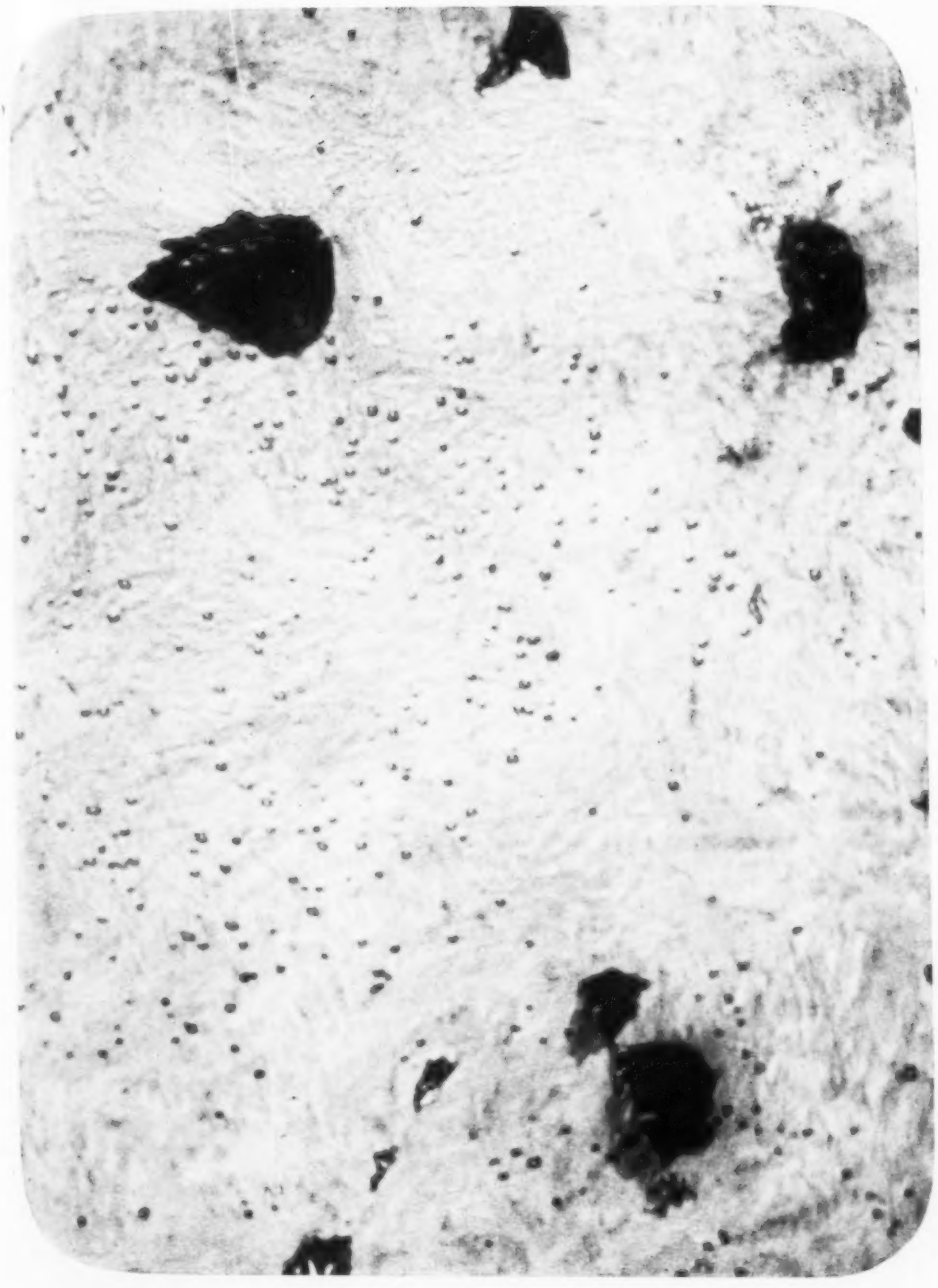


Fig. 36—A specimen of commercial 1.10-1.20%C. steel heated in such a way as to develop small cubic figures in a matrix of austenite and martensite. These cubic figures also measure about 1/100,000 inch on a side. Compare with Figures 33, 34 and 35—Magnification 3230X

Fig. 37—Specimen 25-A very lightly etched to show the twin formation of martensite common with a twinning plane of austenite. Note the lamellar structure of the martensite and variations in shading. Deeper etching would have obliterated the finer details—Magnification 3230X

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evident that the conception[4] of Dr. H. M. Howe, in regard to the crystallization of iron, is probably the correct one. Fig. 32 is after Dr. Howe's diagram and shows the octahedral crystal composed of small cubes. Apparently the line or cleavage structure developed is that of the octahedron and the tiny pits of Figs. 30 and 31 are indicative of the inner structure.

The writer observed occasionally that tiny well defined cubic pits could be seen in the austenite and that these could not mark the inner structure of austenite became evident when most violent etching was required to develop this inner crystalline structure of austenite.

Accordingly to permit of this feature being investigated, specimen 25A was ground well below all previous work, about 1/8 inch of metal being removed, and then polished in the usual way. Every precaution was taken to preclude the possibility of heating the specimen. It was then lightly etched with picric acid and carefully observed from time to time. The etching was continued until martensite was colored quite darkly. Under these conditions it was found that the austenite and the martensite both developed innumerable cubic pits. The specimen was then repolished and etched in the same way with boiling sodium picrate. The figures developed again and stood out in great contrast when they occurred in the martensite because these tiny cubes do not stain with boiling sodium picrate, whereas the martensite stains quite darkly. Whether or not these figures developed, seemed to be a matter of securing just the right degree of etching. If the etching is not of sufficient duration they are not developed, and if continued too long the pits are obliterated.

Figs. 33 and 34 are at 3,230 X and show the conditions which were obtained with picric acid. Fig. 35 at 3,230 X was obtained with boiling sodium picrate as an etching reagent.

Since the pits develop with picric acid and do not stain with boiling sodium picrate, the conclusion seems justified that the austenite has precipitated ferrite (or alpha iron) in perfect cubic crystals. The writer inclines to the view that the presence of these cubes in the martensite may be due to the development of the martensite after the formation of the tiny cubic particles of ferrite and that they are found in the martensite as inclusions,

[4] "The Metallography of Steel and Cast Iron," by H. M. Howe.

about which the transformation from austenite to martensite has taken place.

When conducting some earlier experiments with a commercial steel of 1.10-1.20 per cent carbon the writer found that under certain conditions one of the very early transformations from austenite and martensite to pearlite was a precipitation of ferrite (or alpha iron) in perfect cubic crystals from the austenite and martensite, and that these crystals persisted throughout to the final stage of laminated pearlite. They developed and united so that gradually they became rectangular and finally long narrow bands of ferrite, as found in pearlite. Fig. 36 at 3,230 X shows the very early stages of this transformation, in which the background is austenite and martensite; the dark blotches are troostite and the tiny cubes are ferrite.

In the heat treatment of this 1.10-1.20 per cent carbon steel some tempering action probably took place along the rod because the rod was not heated uniformly and, therefore, the rod would tend to transfer heat along itself from the hot to cold portions while being quenched. With this in mind the writer inclines to the view that some tempering may have taken place in this later preparation of specimen 25A, so that a marked precipitation of ferrite occurred.

That twinning occurs in austenite has been known, and attention has been directed above to the symmetrical arrangement of martensitic needles suggestive of twinning. Fig. 37 of specimen 25A at a magnification of 3,230 X shows distinctly a twinning plane of the austenite, from which twinned martensitic needles have developed. It will be noted that one needle of the twin formation etches more darkly than the other needle, and that both parts of the twin show the finely striated structure and quite marked mother-of-pearl shading. When revolved about the axis of the microscope, the needle which is dark remained dark and the light one remained light, showing that this coloration probably is not a matter of orientation, at least within our present range of microscopic vision. Martensitic development lies wholly within an area of uniform orientation of the parent austenite and martensitic crystals are not found which cross a twinning plane of the austenite. Twinned martensitic crystals are found frequently which have a common twinning plane with austenite, but as previously stated, needles were not found which crossed an austenite twinning plane,

such as shown in Fig. 37. This offers substantial evidence of itself that martensite is a decomposition along crystallographic planes of austenite and, therefore, must possess certain crystallographic planes in common with austenite. Hence, when the austenite has decomposed fully to martensite—assuming that this condition can be fulfilled, although considerable evidence has been secured to the contrary—a new product is at hand, but it is arranged along the octahedral crystallographic planes which prevailed when austenite alone existed. This reasoning holds true regardless of whether all of the austenite is transformed to martensite, or whether some of it is changed to a lower order, because it can be shown that decomposition to pearlite may follow these same crystallographic lines.

In connection with Fig. 37, it is of interest to note the absence of cubic pits of ferrite. Nevertheless, this is the same specimen of which photomicrographs were taken, showing the martensite and austenite containing innumerable ferrite particles. The difference lies in the etching of the surface. The specimen was etched 20 seconds in 5 per cent picric acid for Fig. 37, and this etching is not sufficient to attack ferrite. The slight indistinctness of Fig. 37 is due to lack of a contrasting etch, but if etched more deeply then the ferrite pits begin to develop again.

Conclusions

The Crystallographic Relation Between the Dendritic and Polyhedral Structures

It appears that an iron-carbon alloy may be cast in the form of a cylindrical billet about one inch in diameter and ten or twelve inches in length; hot rolled to a $\frac{3}{8}$ inch rod, and then if a specimen of the rod is heated to 1,260 degrees Cent. (2,300 degrees Fahr.) and quenched in an ice and brine solution at —10 degrees Cent. the metal is trapped in a state which is neither dendritic nor polyhedral, but which is a combination of the two forms of structure. At the center of the rod rather large polyhedral grains of austenite are found separated by an intercrystalline eutectic which, on examination, appears to be iron carbide, in which are numerous inclusions probably of saturated austenite. Sometimes these inclusions consist entirely of austenite, but often they contain well defined martensitic needles. These inclusions may be found in the

very stages of separating from the parent polyhedral grain and passing out into the intercrystalline mass, oriented along crystallographic planes, dendritic in form. As the field under examination progresses from the center of the rod to the outside the dissolution becomes more and more apparent, so that at the outer portion of the specimen the structure is entirely dendritic. Thus it is seen that a very close relationship exists between the dendritic and the polyhedral forms of structure and that probably the difference in form seen under the microscope lies not in the crystal habit nor in the crystal outline, but in the homogeneity of the metal. When the constituents of the metal are so thoroughly diffused that segregation is not apparent under the microscope, then the polyhedral form of structure is seen, but when segregation of any sort prevails selectivity in etching reveals the dendritic outlines which, in the first case, were there but unseen, due to the lack of selectivity in etching. Some remarkable evidences of the persistent effect of dendritic segregation in commercial steels has been shown by Dr. Sauveur[5] and by Dr. Sauveur and Dr. Krivobok.[6]

The Nature of Austenite

Austenite is generally regarded as a solid solution in gamma iron of the usual impurities of commercial steel and of iron carbide. There is some doubt as to the exact nature of a solid solution, and there also appears to be some differences of opinion as to the form in which carbon is held in solid solution in the gamma iron.

The writer pictures a solid solution as a homogeneous union of two or more substances in indefinite proportions, this union persisting in the solid state and being so complete that the individual substances cannot be separated under the highest powers of the microscope. Chemical combination is not implied, since a new compound would then be formed and the separate constituents would cease to exist as such.

Austenite is seen to consist of polyhedral grains. It is clear white and structureless under the highest powers except when it has precipitated tiny particles of ferrite or when it has been etched in a most drastic manner for long periods of time, under

[5] "The Crystallization of Iron and Its Alloys," by Albert Sauveur, in TRANSACTIONS of the American Society for Steel Treating, July, 1923.

[6] "Use of Sodium Picrate in Revealing Dendritic Segregation in Iron Alloys," by Albert Sauveur and N. V. Krivobok.

which conditions tiny cubic crystals are developed. That these crystal outlines are cubic seems beyond reasonable doubt and hence we may conclude that the ultimate crystal form of austenite is the cube.

It has also been shown that two, three or four sets of lines or cleavage planes may be developed in the austenitic grain, depending on the orientation of the grain. That these lines are directly traceable to the geometry of an octahedron has been shown, so that the conclusion may be safely stated that the crystal habit of austenite probably is as pictured by Howe, in which the inner structure is cubic and the arrangement along crystallographic planes traceable to the octahedron.

Austenite decomposes into martensite; it also may transform directly to troostite without passing through the martensitic stage; it may develop a "line" or cleavage structure which appears to be decomposition along crystallographic planes to troostite with the elimination of excess carbide, or it may precipitate ferrite in perfect cubic form.

That austenite satisfies the general conception of a solid solution seems true. It etches very slowly with either nitric or picric acid solutions, and it is stained a faint yellow, if at all, by boiling sodium picrate. Nevertheless, austenite can be shown to decompose and free large quantities of iron carbide. If iron-carbide is held in solid solution then it must be dispersed so that the particle size is sub-microscopic and so highly diffused that iron-carbide ceases to be a separate and distinct constituent. If this is true austenite should not be expected to respond to a test which lies within the scope of microscopic vision.

Other work carried out by the writer points very strongly to the existence of iron in two allotropic forms. As yet substantial evidence has not been found of a third form. It seems probable that austenite is a solid solution of iron carbide in gamma iron, but that the cube is the crystal form of gamma iron and not the octahedron. There is unmistakable evidence throughout the transformations in iron-carbon alloys that alpha iron and iron-carbide are incompatible, and when the opportunity affords they tend to separate. When iron is in the gamma form apparently it converts readily to the alpha state and may form in tiny cubic particles and these particles persist and grow, forming the ferrite of

lamellar pearlite. That a tempering action of some sort is conducive to the formation of ferrite particles seems also to be true, since by modifying the heat treatment a different structure may be obtained and the formation of ferrite held in abeyance until a lower order of decomposition than martensite has been reached. These are matters which the writer hopes may be developed in subsequent publications, but they can only be mentioned here as additional evidence which has been secured and which bears on the work presented at this time.

The Nature of Martensite

Martensite appears to consist of an acicular crystal-like substance, which forms along the octahedral crystallographic planes of the austenite. The crystals of martensite may be likened to feathers in their general shape, since they are usually broad thin flakes with a central rib and they taper toward the ends to sharp points. Sometimes the decomposition of austenite spreads out, so that the martensite, instead of resembling a needle, is fully as broad as it is long, but these areas are always characterized by a central rib similar to the more perfectly formed crystals.

Martensite develops readily from the grain boundaries of austenite. One crystal may develop several spines or branch crystals of martensite arranged along parallel crystallographic planes and the central ribs of these embryo crystals seem to have their origin in the central rib of the parent crystal. Several crystals of martensite frequently meet at a common junction. It seems to be true that martensite is a progressive stage of decomposition of austenite and that once it has started a network of interconnecting crystal forms soon develops.

Martensite etches readily with picric acid but shows a marked selectivity for the central rib to etch much more deeply than the rest of the needle. Martensite also stains readily with boiling sodium picrate and the central rib stains a little darker, if anything, than other parts of the crystal.

Deep etching with picric or nitric acid fails to develop etching pits but does bring out a line structure. The width of these lines is of the order of 0.000006-inch or less. Moderately deep etching of martensite develops a mother-of-pearl appearance. Boiling sodium picrate stains the needles uniformly, save for the midrib.

Martensite is often found with a decidedly granular appearance. This may be due either to partial decomposition to troostite or to the fact that the needle showing this structure is sectioned on a plane almost parallel to the plane of the line structure described above.

That martensite is composed of fine lamellæ seems to be substantiated by most of the evidence. That it is not a solid solution in the sense of the definition propounded also seems to be true because more than one constituent is visible under high magnification and, moreover, martensite responds strongly to both boiling sodium picrate (which austenite fails to do) and to picric acid. Hence the conclusion seems justified that iron-carbide must be present. It must be present in a highly dispersed condition, forming an aggregate or mechanical mixture with iron, probably in the alpha state, the two being deposited along crystallographic planes, thus forming, when etched, a fine line or lamellar structure.

That martensite is very hard is well known and that other transition stages of steel will scratch more readily than martensite can be demonstrated, so it seems likely that the distribution of iron carbide in a highly dispersed state must be one of the contributing factors to hardness, if not the chief factor. If iron carbide is assumed to be held in solid solution in gamma iron, then the transformation to martensite must mark in its early stages a very fine precipitation of this constituent along with iron in some other allotropic form than the gamma state and the subsequent transformations, troostite and sorbite are stages in the process of stratification indicative of growth of particle size by union and stratification of the two constituents—alpha iron and iron carbide. Other microscopic work on the transformations of iron-carbon alloys by the writer seems to indicate very strongly that this is the case.

Martensite develops twins which often have a common twinning plane with the parent austenite. Martensitic development was found always to be confined to areas of uniform orientation of the austenite and in no case was a martensitic needle found to cross a twinning plane of the austenite. This, of itself, constitutes substantial evidence of the arrangement of martensite along crystallographic planes, and it also shows how persistent the original crystallographic planes must be.

The writer wishes to express his appreciation to members of the organization of the Research Laboratories of the American Telephone and Telegraph Company and the Western Electric Company and in particular to H. Clyde Snook, for cooperation and encouragement which he has enjoyed, and to Miss A. K. Marshall and R. R. Ziegler for their assistance in the laboratory work.

He also wishes to thank Professors Sauveur and Boylston for their very able instruction and kindly criticism which has meant much in the success of the work. To Dr. John A. Mathews he is deeply indebted for his kindly interest and advance criticism of this paper.

Discussion of Mr. Lucas' Paper

CHAIRMAN MATHEWS: I think we will all agree that Mr. Lucas has given us a very valuable, constructive paper expanding the use of metallography. We are wondering what he will show us next year when he gets his new equipment. Are there any questions you would like to ask Mr. Lucas, or any contributions to the discussion?

ALEXANDER MACDOUGALL: I would like to ask whether or not the X-rays will detect fractures in the interior of a bar of iron, for instance, a driving axle to an engine.

DR. W. P. DAVEY: In the previous discussion the question referred to me was as to the possibility of discovering flaws in metal by the use of X-rays. Taking pictures of metal to determine the flaws in the metal is quite different from trying to determine the arrangement of the atoms in the crystal and the distance between those atoms. These two types of X-ray applications are entirely different tools for metallographic work. Probably Dr. Lester, in his paper to be given on Thursday morning will contribute a great deal more to the subject of radiography than I can, for I have not done any radiographic work on metals for a number of years. The greatest thickness of metal that I have been able to penetrate is three-quarters of an inch, but I am sure that Dr. Lester has been able to beat my record by several fold. Probably the answer to that question had better be postponed until Dr. Lester presents his paper. My work for some time has been on the structure of crystals and I want to say that I do not feel that X-ray work of any sort replaces in any way the ordinary photomicrographical work. It is an extra tool, it is something in addition; it is not something to supplant existing metallographic methods. Mr. Lucas is to be congratulated on the kind of work he has done, and it is wonderful how the two methods fit in together and give the same result. I think the two methods are mutually co-operative; one does not replace the other in any sense.

Mr. Lucas spoke of getting octahedral faces from the cube by splitting up a lot of little cubes so as to build up an octahedral outline. It is not necessary

to do that, because austenite has the face-centered cubic structure, and it is easily possible for a crystal of the face-centered cubic variety to be bounded by octahedral planes. I was much interested to see Mr. Lucas' picture of martensite showing the very small size of the crystals, because the lines in the X-ray diffraction pattern of martensitic steel are pretty fuzzy. This might be taken to mean either that we have very small crystals, or that the crystals are badly warped. Dr. Jeffries stated to me yesterday that the small-crystal interpretation was much more reasonable, and Mr. Lucas' photomicrograph seems to bear this out.

F. F. LUCAS: I am an attentive listener in the matter of X-ray analysis, and am more or less in deep water on that subject. I was interested in bringing out the fact that we have been able to get two forms of structure, one of which apparently could be traced back to the crystallographic planes of the octahedron.

In connection with the nature of martensite, our evidence seems to indicate that martensite is composed of an exceedingly fine mixture of iron and iron-carbide. My assumption is that we get this granular or mottled appearance, which I have been able to show in martensite, because it is so fine a precipitation of these constituents that it is barely resolved with our present equipment. When it is possible to increase our ability to resolve detail, we should then be able to get distinct images of the separate constituents. It is probable that the laminated structure often found in martensite is closely related with the crystallographic planes of the parent austenite. An examination of Fig. 25 will disclose that details of structure do exist along the edge of the martensitic needle as austenite passes to martensite.

DR. ZAY JEFFRIES: I would like to take this opportunity of congratulating Mr. Lucas on the splendid photomicrographs, as showing with the microscope, things which have never come to my attention before, and which I think perhaps are entirely new, judging from the amount of literature that I have looked over in connection with the study of martensite. It certainly is a great achievement in photomicrography, and I know that we will look forward with very great interest to learn of Mr. Lucas' work in connection with the ultra-violet light microscope.

There are some features in connection with this study which might be suggested for the present microscope with the technique which Mr. Lucas has at hand. He has plunged into the deep water in connection with the type of martensite which he has studied, namely, martensite which has formed from high carbon austenite. The carbon content of the austenite was so high that primary precipitation of cementite may have taken place at a high temperature, above 1650 degrees Fahr.

It would appear that an easier method of approach to the study would be through the low carbon martensite. Starting with pure iron, the ordinary water quench does not produce martensite, but Mr. Rawdon and others at the Bureau of Standards have apparently produced martensite in electrolytic iron of 0.004 per cent carbon by fusing it very quickly under an arc and allowing a very small particle of molten metal in contact with relatively cold metal to receive a degree of chill which is impossible in an ordinary water quench.

Such material apparently is nearly glass hard and responds to all of the tests for martensite. That would be substantially a carbonless martensite.

Tests are now under way in other organizations to check these experiments, and certainly within another year we will have additional evidence to support the work at the Bureau of Standards on that point. As the carbon content increases, there is a small amount of carbon which will permit the retention or production of martensite under an ordinary water quench. Major Smith of the Lamson and Sessions Company has been doing some work on increasing the rate of cooling of steel by applying the water under pressure, and he has succeeded in producing properties in steel containing 0.09 per cent carbon, which we did not suspect could be obtained with such steel, and the structures he tells us, are martensitic.

There is a composition then, low in carbon with which we can produce martensite which is relatively soft, having an elongation of over 40 per cent, and which responds to the ordinary microstructure for martensite. There is a composition still lower in carbon with which we produce a material which is recognized as ferrite. Between these two compositions I would think would be the most fertile field for microscopic study to elucidate some of the problems in connection with the microstructure.

I would like to just touch on one point in connection with the conclusions. The microscope is no tool to use in connection with the interpretation of atomic structure; for example, the matter of whether carbon or iron-carbide exists in the austenite in solution. The microscope can give us, I think, very little evidence on that point. What the microscope tells us is, that when the particles precipitate and segregate to a size large enough to be seen with the microscope, the product is cementite. It may tell something in connection with etching tones, but there is a great deal of evidence in the direction of the manner in which carbon exists in austenite, and there is considerable evidence, although it is largely indirect, but I think much better than the microscope, in connection with the state of the carbon after the quench. Westgren's late X-ray work is in the direction of the carbon being present in the austenite as individual carbon atoms and placed in between the iron atoms of the space lattice. He has obtained that result from two directions; studying two different steels, one a manganese and the other a high carbon steel. He finds that the carbon spreads the lattice in both the manganese steel and the high carbon austenite.

In connection with the manner in which the carbon exists after the quench, and when martensite is formed, the evidence is indirect, but I think it is much more conclusive than any microscopic evidence could be. Professor Honda has shown that in freshly quenched martensite, he does not get the magnetic point, due to cementite. After reheating to a temperature of 400 or 600 degrees Cent., the cementite point appears in the magnetic study. He has also worked that out in connection with heat energy. The transformation, austenite to pearlite, involves heat in two directions, one the transformation of gamma iron to alpha, and the other the formation of the iron-carbide or cementite. He finds that on the quench, the heat evolved due to the change from gamma-iron to alpha-iron, is given off, but the heat due to the iron-

carbide formation is not present until after a reheating, or until after time has been given for the iron-carbide to form in the martensite.

Other evidence in that direction is by Brush, where he finds that immediately after steel is quenched so as to form martensite, heat is evolved and contraction begins to take place, all of which is in line with the other indirect evidence to the effect that the iron-carbide forms and the particles grow after the gamma- to alpha-iron change has taken place. The results on the spots of ferrite in the cubes look extremely improbable from any standpoint, at least any metallurgical standpoint, that I can possibly think of. I can not say that they are not there and that they are not ferrite, but there is a possibility that they may have been precipitated from the etching solution. That has happened in many cases. That is only one solution, but the statement made by Mr. Lucas that they are apparently ferrite, which has been precipitated from the austenite, I think should be taken at this time with a great deal of reservation. I do not wish to detract in any way from the very valuable paper that has just been presented, because my entire feelings toward the paper are those of praise.

CHAIRMAN MATHEWS: Mr. Lucas, have you anything to say in conclusion? There is another session this afternoon, and most of us are about saturated now with the information we have had during the last three or four hours.

F. F. LUCAS: I want to thank Dr. Jeffries for his very able criticism of the paper. The microscope, of course, can not be expected to show the ultimate arrangement of matter in austenite. It is possible by very precise laboratory methods and by logical reasoning derived from comparative methods to arrive at a reasonable interpretation, and these comparisons have been drawn more for the purpose of definining the structure of martensite than that of austenite. For instance, if in a given field under view, we find that austenite fails to respond vigorously to a test which is known to select iron-carbide, but that martensite does respond, then the inference seems justified that if iron-carbide is present in austenite it must be so highly dispersed (solid solution) that it does not come within the range of microscopic visibility, and hence should not be expected to respond to a test which can only come within that range. If the carbon is present in austenite as carbon, then I have no knowledge at present that boiling sodium picrate should be expected to select it, even if present, in a particle size within the range of microscopic vision. Martensite in the same field does respond to this test, and it also responds to the usual reagents such as nitric and picric acid. I think we may reasonably infer that in martensite both iron-carbide and iron must be present as separate and distinct constituents.

In regard to the small cubic figures which apparently are ferrite, it may be said that the evidence all seems to point to their existence under tempering conditions.

After reviewing the notes of the discussion, the writer might add that he has examined under high powers many different specimens of plain carbon steels of various carbon contents, and has never yet seen one which was wholly of martensite. The specimens either contained austenite and martensite (and also sometimes lower orders of decomposition) or martensite and lower orders

of decomposition. This note is inserted as a caution that a structure presumed to be martensitic by the usual methods of metallographic examination may in reality be rather complex mixtures.

The suggestion that the small cubic figures may have been produced by precipitation from the etching solution does not appear to be the case, and moreover the figures are quite clearly pits and not elevations. This does not take into consideration the fact that precise methods of preparation are employed and that an objective of exceedingly short working distance and high primary magnification is used so that any extraneous matter would appear monumental in comparison with the minute structural details of the metal.

CHAIRMAN MATHEWS: Mr. Lucas very thoughtfully arranged these microphotographs on the boards here for you to examine more at your leisure. In some respects the original photographs are more satisfactory than the pictures shown on the screen.

J. S. VANICK (written discussion): With the exceptionally good photographs with which the author illustrates the structure of a 2.65 per cent carbon iron quenched from 1260 degrees Cent. (2300 degrees Fahr.), my curiosity is aroused at the caution with which he describes the resulting interdendritic constitutent of Figs. 2 to 10, as the iron-carbon eutectic. Surely a "chilled" cast iron structure should be expected in a high carbon iron quenched from a temperature in the partial-fusion range. The micrographs beautifully illustrate the structural developments during the fusion of the solid in contrast to the more familar structures of the solidification of the liquid. Perhaps more attention might profitably be expended upon the former process.

The development of the martensitic pattern along the austenitic cleavages and grain boundaries is not an original concept and should be expected. Indeed, the well-known Widmanstatten structure is a macroscopic manifestation of the same martensitic pattern which would be expected to appear when an octahedral grain passes through a phase change; or decomposition or precipitation along the cleavages is induced. In the case of meteorites or steels which had passed from the gamma to the alpha iron stage, the entire alpha mass may show the pattern characteristic of its gamma iron predecessor chiefly because the expulsion of alpha iron during the early stages of cooling occurs along the octahedral cleavages and at the grain boundaries. Thus, as explained by Osmond and repeated by Howe, the alpha iron crystallizes on the gamma iron axes, and the martensitic pattern of alpha iron is a pseudomorph of the pre-existing gamma iron structure. The acicular martensite Mr. Lucas describes, the triangular figures of alloy steels (especially of the hypoeutectoid nickel-alloy type) and the macroscopic features of certain meteorites are all manifestations of the octahedral assembly of austenite.

The expulsion of ferrite as small cubes in the low temperature tempering of a strongly hyper-eutectoid iron would seem to require more convincing evidence than the author allots to this phenomenon. The occurrence of cubic or hexahedral etching pits in the solid-solution matrix would not be at all surprising.

I find much of my confusion arises from the author's indiscriminate use

of the terms "crystal habit" and "crystal form" and the failure to distinguish between "grain" and "crystal" in the sense in which these terms are now frequently used. Thus, from the history of the crystal structure of iron, available data points toward austenite as a gamma iron entity, certainly as a cubic "form" and predominately in an octahedral "habit."

Along this line of thought, the discussion involving Figs. 30 and 31 in an attempt to establish the "crystal form" of austenite on the basis of the occurrence of minute cubical etching figures occupies much of the author's efforts, when the form of the crystal or lattice unit is unquestionably that of the cubic or isometric system, while the grain is obviously octahedral as the author points out from the plotting of the cleavage plane expulsions of martensite. It is discouraging to attempt to reconcile the author's views in the discussion regarding austenite "the inner structure of which is cubic and the arrangement along crystallographic planes traceable to the octahedron," followed by the statement in a later paragraph that "the cube is the crystal form of gamma iron and not the octahedron."

Apparently an effort is being made to picture the resolution of the austenitic octahedron into smaller cubic units, but a definition of the crystallographic terms used would assist in clearing up the conflictions which the use of terms with interchangeable meanings introduces.

The refined methods of microscopy which the author proposes may resolve enough details which with a study of the features of etching figures and pits may demonstrate or disprove the presence of either physically distinct sub-divisions of the structure of a grain or manifestations of directional interatomic force-groups which embrace dimensional space in the grain structure.

SYMPOSIUM ON METALLURGICAL EDUCATION HELD AT THE SIXTH ANNUAL CONVENTION OF THE SOCIETY, BOSTON, SEPTEMBER, 1924

IN opening this meeting, the chairman, Dr. O. E. Harder, University of Minnesota, announced that the written contributions to the symposium would be presented and then they would be opened for general discussion.

The first paper on the program was that of Professor Stoughton, but due to his absence, it was read by H. C. Knerr, chairman of the Philadelphia chapter of the Society.

What Constitutes the Best Metallurgical Education

By Bradley Stoughton

THE BEST education for a metallurgical engineer is the broadest one. It is the one which gives a man intelligence along metallurgical, engineering and economic lines, and which produces a sound mind in a healthy body. We do not admire so much a head bursting with knowledge, as we do one which can think straight and which knows where to find the available information on any subject when the need for it arises.

Intelligence, accuracy and industry are the fundamental qualities upon which a good metallurgist's character is built. If to this we add judgment, courage, resourcefulness, we have a man who will ultimately become general manager and president of his company. Success does not depend so much on the information one carries away from college in his head, as upon one's ability to acquire information and to apply it to make money for his employers. It is the foundation, background and character which counts, since the information can quickly be acquired in practice, although one who starts with a good fund of information has an advantage over the same type of man, but who is without metallurgical training.

We have an excellent example of this two-fold nature of the qualities which make success, at many metallurgical plants, where there are men who know a great deal more about metallurgical practice than the college graduates who come there, but who have not the training in fundamental principles to intelligently and accurately control some of the technical operations. When they have native intelligence, industry and ambition, they are deserving

of that technical training which will enable them to go far, but their information, however vast, is only valuable in proportion to their knowledge of principles. I hope that those of us who are engaged in metallurgical education may be able to give these men the helping hand which their aspirations merit.

Returning to the college man, we would rather see a graduate well grounded in the fundamental subjects, even if time has not been available to give him much metallurgical information. Metallurgical information without well-balanced training in the fundamentals will carry a man along with a wasting energy somewhat like the propulsion of a skyrocket.

What was it, then, we would call a well-balanced course with sufficient fundamentals? Our basis for such a course would comprise:

One-half (50%), of the fundamental subjects, such as mathematics, languages (including English and foreign languages), chemistry, physics and economics.

One-third (33%), applied engineering and applied science, including drawing, descriptive geometry, graphic statics, heat engines, dynamos and motors, hydraulics, strength of materials, mineralogy, economic geology, etc.

One-sixth (17%), metallurgy.

The training in fundamental subjects should give the student the basis for acquiring sound judgment. The ability to speak and

Fig. 1—A Balanced Four-Year Course in Metallurgy.

write English satisfactorily and attractively should enable him to acquire self-expression and the ability to "sell" himself and his ideas when necessary. The one-sixth of metallurgy, which is all that would seem to be available for graduates of a four-year course, should give reasonable equipment for starting professional work

under favorable auspices. It is equivalent, in the ordinary four years' college course, to 12 hours' work a week for a continuous period of 3 years. How, then, shall we divide *this* time to get the greatest benefit from it? It seems to us that it can be best divided as follows:

Two-thirds (66%), theoretical instruction;
One-quarter (25%), instruction in the laboratory;
One-twelfth (9%), instruction at metallurgical plants by visits and inspection.

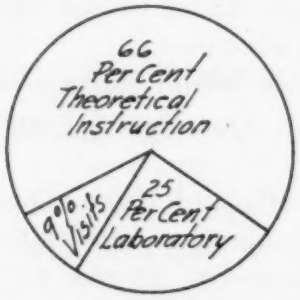


Fig. 2—Sub-Division of Metallurgical Instruction.

The object of laboratory instruction should be to familiarize the men with the use of instruments and to crystallize in their memories the fundamental metallurgical principles learned during the theoretical instruction. Minimum time should be spent on the manual side of the operations and on manipulation, and the attention should be concentrated as much as possible, on the application of principles underlying the processes relating to chemical metallurgy, physical metallurgy, mechanical treatment, heat treatment and structural metallography, which the student has already learned in his lectures and recitations. The time available in a four-year course is not sufficient to train research investigators, nor yet expert heat treaters, but the student can be given the foundation upon which to build expertness and excellence. Above all, he should be given an insight into the value of research and its growing importance in industry. He must be taught and retaught the danger of unapplied, or uneconomic idealism.

In the theoretical instruction, the student should be given a thorough acquaintance with the methods of quickly locating information in the literature of all the metallurgical countries of the world. He should be taught to make books his servants, and that a

library is as valuable to one who knows how to use it as a Maji or a Jinn was to be the possessors of magic rings in the stories of the Arabian Nights. He should be taught how to use to the full, the Engineering Societies' Library in New York, either when his work obliges him to live in New York or in a distant city.

The one-twelfth time devoted to visits to metallurgical works would correspond approximately, in the ordinary four years' college course, to an average of one afternoon's work a week for one academic year. To these visits, the students and instructors should go "arm in arm," so to speak, there being only 5 or 6 students to each instructor. Only one operation should be studied at a time. The student should be thoroughly and well informed in advance what he is to see, and should concentrate his mind on the application of the principles in actual operation. He should be obliged to prepare a report on what he has seen, consisting not of a description of the details of the apparatus and the details of his visit, but an impersonal discussion of the technical features of the apparatus and processes. In this way, going from operation to operation, and from metallurgical works to metallurgical works, the important part of metallurgical training will soak into the student's mind and remain fixed in his memory more effectively and advantageously than by all of his theoretical instruction put together. In most cases, it is also desirable for the student to spend a part of one summer in actual employment at a metallurgical plant, but during his employment his mind is too much distracted by the question of routine duties, wages, "quitting" time, and other questions for him to get the full benefit in preparation for his life work. We consider this a great help to the student, but not in any sense the equivalent of plant visits with intensive study in small groups under the instruction of a professor.

We do not believe that the so-called "cooperative courses" give the immature student a practical or well-balanced knowledge of the application of principles. It is one thing to be conscious of metallurgical knowledge, and an entirely different thing to have metallurgical knowledge in your consciousness; just as it is one thing to be vaccinated for small-pox and another thing for it to "take," and thereby become effective. Laboratory exercises, and plant visits under supervision and instruction, crystallize knowledge in a student's consciousness, as well as form the habit of coordinating

science and practice and transforming ideals into actualities. A tendency to *ideology* may be accentuated in a student's character by a co-operative course in metallurgy, where he is for a part of the time studying principles without application, and the remainder of the time in a subordinate position, without responsibility, to apply principles in practice, and urged only by easily-forgotten precepts of his teacher, to watch how others are making the application. It is a matter of observation that the laboring men are the dangerous ideologists today, not the clergymen nor the professors.

The second paper on the program was presented by Dr. S. L. Hoyt, entitled, "On Metallurgical Education." This paper was published in full in the August, 1924, issue of TRANSACTIONS.

The third written contribution was a paper by Professor Demorest, Ohio State University, which was read by Professor H. M. Boylston. This paper follows:

Metallurgical Education

BY D. J. DEMOREST

WHEN we discuss educational matters of this nature we must get a clear idea concerning the persons who are to be educated; we must decide whether we are going to plan to educate the comparatively few gifted students or whether we are to plan to educate the average kind of student knowing, of course, that there will be a sprinkling of geniuses in this group of students. Let us assume that we are planning to offer metallurgical training to the "Run of Mine" students, trusting that the genius will take care of himself, which is a fairly safe assumption.

The writer believes that there is little doubt that our educational courses (or, better, curricula) are tending to become too "broad" and diffuse rather than too narrow, and the result of this so-called broadness is also a tendency to make the student pay the cost for our lack of definiteness of aim by requiring him to take a large number of courses and increase the years required for graduation. The present writer does not believe that lengthening the college life of a student beyond four years gives him as much additional advantage in his life as that extra time gives him if he spends it earnestly engaged in a "job." If he is the

kind of man who would have profited from additional time spent in college he will profit still more by observation, study and experience in his job. If he is not growing in capacity and ability in his job he would not have done himself any good by spending additional time in college. Of course, there is the occasional man of typical research ability for whom a more extensive training in college is advantageous.

Assuming then for the purposes of this discussion that a four years' course in college is adequate, the question is—how can we make these four years most effective? If the writer were given the chance to build a school of metallurgy from the bottom up, this would be the main effort he would make to secure the maximum effectiveness in metallurgical training (and the same for any other kind of engineering training)—he would have the fundamental courses of chemistry, physics, mathematics, economics and design (engineering drawing) taught from the very beginning and through three years, not by chemists, physicists, mathematicians, economists, etc., but by men of metallurgical experience and background who were capable specialists in chemistry, physics, etc. Running through the entire four years I would have a weekly lecture on history, literature, art, etc., which would be required of all students, but which would be used more as a matter of inspiration and enlightenment rather than a course requiring reports, examinations and similar drudgery. The fourth year would be given up largely to intensive training in the application of the methods of chemistry, physics (metallography), economics, etc., to the solution of specific problems of metallurgical industry.

This is something of an impractical dream, with our great universities organized as they are, but a student who could not get thoroughly prepared for a useful life in metallurgy under these conditions would be hopeless as a metallurgical engineer. The problem, you see, is merely a phase of the problem of teaching or perhaps better stated it is the problem of the selection of teachers.

The fourth written contribution to this symposium was a paper by Dr. Kotaro Honda, Tohoku Imperial University, Sendai, Japan, which was read by the chairman, Dr. O. E. Harder.

The Education of the Research Men

By Kotaro Honda

As a metallurgist, the writer is still young in experience and has limited himself in the past to only research and has, as a matter of fact, little knowledge in teaching this branch of science, and therefore he feels that he is not fully qualified nor able to discourse extensively on the subject. However, he will so endeavor to tell you through his experiences what he believes is the way to educate the research men in the field of metallurgy. This problem is also in relation to the metallurgical education being very important in the progress of this science as well as in the development of the industries of steel and other alloys. To make the research men, it is important that these men have gone through the courses of advanced education, for instance, a graduate of some university or an institution of a similar standing. Since in the present day, metallurgy has made great progress and has moved from the qualitative to the quantitative investigation, the metallurgists must have much of the preparatory knowledge of chemistry and physics, and also to a certain extent the knowledge of mathematics. From what the writer has witnessed in university education, at least in that of his own country, the students of metallurgy have been pressed none too hard in these preparatory subjects, and hence it is his belief that to obtain promising research men, graduates of the metallurgical department have a great need of conscientiously studying the subjects of chemistry, physics and mathematics. According to what the author has gathered through his own research institute, the advanced graduates of physics or chemistry, if they are afterward educated as metallurgists, show better qualification in the research work of metallurgy. This shows that the research men in the field of metallurgy must have the preparatory knowledge in the subjects mentioned.

In educating these graduates as research men, what is the best possible way to lend our thoughts to them? These graduates having already the preparatory knowledge essential to the study of metallurgy must be given a subject of investigation and be made to study the literatures connected with the given subject. The subject of investigation must be at first of such a nature that it is very easy and its result of experiment may be predicted by an academic mind. In this way the investigation could be completed without hardship

in half a year or a year, and thus encourage and give confidence to the research men to carry further their work. If, on the contrary, a difficult subject be first given, it may be possible that the investigation may not be completed even after a hard work of one or two years; in this case, they are disappointed and discouraged from carrying on further study. The writer knows from his own experience that research work does not generally progress smoothly, many difficulties being met with. In his experiments, he has sometimes encountered so many difficulties that often he has thought of giving up the experimental work; but when the experiments were completed with a good result, the difficulties met with were forgotten and as a result his rising spirits encouraged him to experiment further with another subject. Thus in any research work, many difficulties are always encountered, and therefore if a successful result is not attained, it often discourages the investigators. To guard against such an occurrence it behooves the teacher to select simple problems for beginners and gradually work to the harder ones. After completing two or three investigations, the research men will gain confidence and knowledge and they will feel and be equal to the task of research on their own initiative. According to what the writer has witnessed, there have been many occasions in which those who had not a brilliant brain at first, but were very diligent men, acquired after several years, the necessary knowledge to carry on research work in the most enlightened manner.

Next we shall discuss the relationship between theory and experiment. In research work it can be performed theoretically or experimentally, but both are necessary, each to the other, for the development of the work. The theoretist often disregards experiments and the experimentalist disregards theory, but this is just a point which needs to have the careful consideration of the research worker. To be exact, the experiment is really to test the consequence of theoretical considerations and to attain the best result should be conducted with primary considerations for the outcome of theoretical research. It is the truth as Sir Rutherford said, that "experiment is not successful, unless it is controlled by the theoretical prediction." Of course during experiment, unexpected discoveries are sometimes made, at which moments the investigation should be reconsidered theoretically and the experiment should follow the principle laid down. Often the experi-

mentalist becomes so absorbed by his experiment that it is not seldom that he forgets his primary object, and this is to be watched. During experiments there are times when the absence of any theoretical principles to follow produces not a few mistaken results of the experiments that are often believed. These mistakes remain as correct and make an obstacle to the theoretical consideration, until they are corrected through elaborate experiments. In short, theoretical considerations give birth to experiments and the results accrued therefrom are applied in further developing theoretical considerations, etc., thus resulting at last to a very important consequence.

During the writer's recent journey he has met and talked with many scientists and has visited and seen institutions and laboratories of metallurgy, but if he were to give his judgment on the present day, it would be necessary for him to say that there is a more or less widespread tendency to disregard the theoretical side of this branch of science. It must, however, be remembered that theoretical researches must always be the primary consideration of experiments. Thus the great results attained by Sir Rutherford through comparatively small efforts is attributed to the fact that his theoretical considerations are of extraordinary quality. Again Lane predicted through the theoretical consideration of the nature of the X-ray, the diffraction phenomenon in crystals and confirmed it experimentally, and laid the foundation of the invaluably important knowledge concerning the structure of matter. On the other hand, if experiments are not founded upon theory, the results obtained do not turn out to be very important. Hence in the institute, with which the writer is associated, when it is desired to begin an experiment, every consideration is closely given to the points just mentioned.

With this, what the writer wished to say has been concluded, but he would like to add a few words concerning the founding of a co-operative research work in metallurgy between America and Japan. There is a maxim, that in science, there are no boundaries nor barriers. In proving this fact, it is with a deep appreciation that the writer recounts the time when he was honored as your guest while on his way to Europe last April, at a time when the immigration bill was causing no light concern in the relations between Japan and America. And, gentlemen, does

not the present moment as the author stands on this platform speak for itself? Again saying that there are no boundaries in science, by increasing scientists who disregard boundaries for the common happiness of mankind, international quarrels and misunderstanding, can be eliminated. Through this meaning, we metallurgists feel and believe that there is an urgent need to do the co-operative research work between America and Japan. In promoting this plan, the best way, it would seem, would be by collecting contributions from interested sources for the financing of two or more research fellows of metallurgy from Japan annually to do research work, say at the Bureau of Standards or some accredited institution, and to make the enterprise of mutuality, there should be sent from this country a similar number of research fellows to Japan, say to the Imperial University. This exchange of research fellows will not only prove to be a service rendered for the progress of metallurgical science, but will no doubt prove greatly beneficial to the best interests of both countries. Drawing from this same contribution, it might also be a feasible idea to exchange professors for the purpose of reciprocating in metallurgical knowledges. In regard to particulars for this co-operative research work, a small committee should be established to handle its minute affairs, and through contributions, a definite annual fund should be made lasting for about two years, to meet on one hand, the expense for the financing of this work, and on the other hand, to further good relations between the two countries. Therefore, the writer appeals to you for your best efforts for the materializing of this proposition.

Within the last 60 years, the relations between our countries have suffered minor disturbances, but in general the intercourse between America and Japan has been of a happy character and even today while there seems to be a slight misunderstanding, we are confident that our friendship is progressing steadily toward a firm foundation. At this moment when the handshakes of the metallurgists of both nations are absorbent of the best intent and good will, may the writer ask that you give your best efforts not only for the sake of metallurgy, but for the purpose of furthering the ends of a peaceful understanding that a nucleus may be created crystallizing our sincerest wish.

CHAIRMAN HARDER: Within the past few years there has come into the

field of metallurgy a new method of investigation, the importance of which is probably only partially realized at the present time. I refer to the X-ray method of analysis. This type of investigation will probably be applied to a redetermination of practically all of our consitution diagrams.

Considering the importance of this subject up to the present time and what it offers for the future, I feel that we are particularly fortunate in having Dr. Ancel St. John to discuss for us X-ray methods in metallurgical education.

DR. ANCEL ST. JOHN: Mr. Chairman and gentlemen. In view of the well known congestion in the metallurgical educational programs and the difficulty of presenting in four years all that the students really ought to have, it is with a considerable amount of hesitation that I suggest adding anything more. However, I do feel that the methods that have been developed for the use of X-rays, both in research, along the lines of crystal analysis, and in practical shop application as in the radiography of metals for detecting internal defects, make it necessary to introduce into the educational program a definite consideration of X-rays and their possibilities.

The importance of crystal analysis has been emphasized by Dr. Jeffries in his lecture in New York last February on the trend of physical metallurgy, and by Professor Mathewson in his talk on the same subject before the Franklin Institute last week. You yourselves have seen the somewhat amazing information that has been disclosed and explained by Dr. Lester during this very convention.

I also want to emphasize that while such talks as these—the lecture by Dr. Lester, the lectures by Dr. Jeffries and Professor Mathewson, the paper that Dr. Davey gave last Tuesday morning, and the talks that Prof. William Bragg and his son have been giving about the country, and those that I have been presenting before various groups of steel treaters—expose you to X-rays, I am afraid that for the most part this subject is not understood by the younger generation, for whom it is so necessary.

Professor Harder has mentioned that he believes that the constitution diagrams are going to be completely reconstructed, if I may use that expression in terms of X-ray analyses. There are not enough men available who are qualified to do that sort of thing at the present time to accomplish it within our day. We must train our young men, consequently, it is becoming necessary to consider ways and means of introducing adequate training in the methods of X-ray crystal analysis in the metallurgical courses, and also of introducing a more than superficial knowledge of the use of X-rays in modifying and improving shop practices.

I have very little at the present time to suggest as to these ways and means. I rather think that the eventual result is going to be that in the larger institutions it will be decided that X-ray analyses have enough to offer to the chemist, to the mineralogist, to the physicist and to the metallurgist, so that instead of having a chair of applied X-rays in the metallurgical department, the school of engineering or the department of applied science under the faculty of physics or the faculty of chemistry, that they will have a sort of a revolving chair in which during a portion of the year

the incumbent will address himself particularly to the applications in chemistry, during another portion to the applications in physics, and during a third portion to the applications in metallurgy, and so on. The actual time spent in considering the specific applications may not exceed a total of two weeks or a month. It may be distributed, perhaps, every week or so throughout the year to each field, or it may be concentrated in a single month.

But pending this, it seems to me that it will be worth while to enlarge upon what has been done. Either last spring or during the summer, at Pennsylvania State University, Dr. Davey gave a series of lectures on X-rays to the students and such members of the faculty as felt that they also might sit at the feet of someone who knew a little bit more than they did about recent developments in this new realm. Professor William Lawrence Bragg gave a similar series of lectures recently at the University of Michigan. Perhaps this is the way that for the immediate future the problem of giving a vaccination of X-ray knowledge to the present generation may be taken care of, with a reasonable hope that in some of the cases at least it will be understood sufficiently for the students to be inspired to elect as a thesis subject a study of the constitution diagram of some binary alloy in terms of X-ray analyses combined with all the other forms of analyses that we already have available. So that for this particular binary there may be available, within a reasonable time, a set of consistent data on the atomic arrangement, the mechanical properties, the melting points, the thermal transformations, the density and so on.

In order to bring this about it is undoubtedly necessary that the demand be created. I very much doubt if there is any university or technical school in the country that is going to volunteer to introduce any such thing unless they have an idea that there is a demand for it. With the calls that are now existent upon educational funds, trustees must think twice or thrice before they decide to devote dollars to any particular purpose. It seems to me that this organization is perhaps a very suitable one to begin creating such a demand. We want to have men who can take our problems and handle them in terms of X-rays. Where are we going to get these men? Are we not justified in bringing pressure to bear upon those who conduct educational institutions, to prevail upon them to consider favorably the introduction of some sort of X-ray work into their own educational program?

H. M. BOYLSTON: I agree very heartily with Dr. St. John in his suggestion, and I hope that the Steel Treaters will consider it. I think that we ought to have a series of articles printed in TRANSACTIONS on the elements of X-ray spectrometer work. This would be one way to begin. Data sheets might also be prepared on X-ray spectrometer practice. Perhaps Dr. Davey would be willing to have us consider printing his series of lectures. As Dr. St. John says, if there are going to be more than a few men to develop this branch of science, we must have men trained to carry on the experimental research work and men who are prepared to help teach the younger men so that they may fall into line at the proper time.

In considering the whole matter of metallurgical education, as Prof.

Demorest remarked, we must differentiate as to the kind of student we are planning to teach. I agree heartily with Dr. Hoyt when he says that he believes the indiscriminate examination of large numbers of heterogeneous specimens is wrong for any kind of a student. It is a little more work for the teacher to prepare a systematic series, but it can be done and ought to be done, and it is being done.

I agree with Dr. Hoyt that we should specialize on the principles of any branch of metallurgy, but perhaps others will get the same impression of his paper that I did when I first read it, namely, that perhaps he is putting too much pressure on theory. You can teach a boy to swim in two ways, first, by gradually getting him accustomed to water and teaching him the strokes and sending him into shallow water to strike out and try to keep his head in the proper position, and the second it to throw him in the deep water and let him swim out.

We can very easily throw the young student—by that I mean anyone up to the fourth year in the ordinary engineering school—into deep water; he may swim out and he may not. I believe that principles and theory should be accompanied by some practical work, some training in technique. I do not think Dr. Hoyt meant to deny the value of that, but I think some may get that impression from reading his paper.

Personally, I would rather put the phase rule in the last chapter. I find that my students absorb it better then. That is, perhaps, a matter of taste, but that is my experience from some 18 years of teaching. I have followed the style of Dr. Sauveur, who has had about 27 years of teaching experience in metallography. I find that if the student is led gently up to the theory of metallography, allowing him to use his hands and his eyes in the preparation and examination of specimens simultaneously with the study of what to him may be a dry text, he will become interested sooner than if he were plunged immediately into the matter of constitution diagrams and the phase rule. I may be wrong, but that is my viewpoint. I have checked this up with other teachers and also by questioning the students themselves after they have had a chance to read other books which do take up the purely theoretical considerations first.

H. C. KNERR: Two matters have been brought before the meeting upon which we should take some action before adjournment. One is the suggestion of Dr. Hoyt, in regard to showing our appreciation to the work of Dr. Roozeboom, and the other is the question brought up by Dr. Honda. If I may, I propose that it might be in order for Dr. Hoyt to put a motion before the meeting on the subject which he brought up.

DR. W. P. DAVEY: I disagree violently with one part of Professor Demorest's paper. I have never taught metallurgy, but I do know a few things about the effect of research work on the status of a technical subject. If we could stop all research work today it would undoubtedly be a fine thing to have all the students specializing in physics taught all their subjects by physicists; all the chemistry students taught physics, mathematics, language, etc., by chemists; and all the metallurgical students taught physics, chemistry, geology, etc., by metallurgists, and so on with all the

other technical courses of a modern engineering school. Whether we like it or not, research is going on and is going to continue to go on. That means that it brings in new viewpoints and new discoveries, and that process is going to continue to change our present theories and present practice.

Suppose, for instance, that ten years ago we had started out to follow the suggestions in Professor Demorest's present paper. Suppose that there had been a school of metallurgy and metallography in which all the physics were taught from the standpoint of the metallurgist. How much would they have learned about X-rays? How much of the electron theory? Nothing would have been known about it. We would have been behind the times before we even got started.

Suppose we started out today teaching a metallurgical student physics strictly from a metallurgical standpoint. Well, I am willing to wager that five years from now there will be as much agitation in favor of teaching the electron theory and the electron constitution of atoms to metallurgical students as there has been today to teach about X-rays. Why? Because it is the way a technical subject advances. Research work in metallurgy is inevitably going to tie metallurgy up to the electron constitution of atoms.

Now where are you going to stop? No one has the ability—and I say that with all due respect to every one present here—to say what part of physics, chemistry, or mathematics is going to be useful to metallurgists ten years from now. For that reason I agree with Dr. Hoyt rather than Professor Demorest in the matter of teaching pure science. We ought to have pure science taught for every technical subject, and taught by a pure scientist, because no one knows what branch of that pure science is going to be needed in the next year. At present a man in metallurgy must know enough to take care of his microscope, but it is not going to be very long before every metallurgist will have to be conversant with the ultra-violet microscope as well as the ordinary one. Would the average man want to study about ultra-violet light and its refractions? Ordinarily not, but he is going to have to know about it. He will some day need to know about the theory of chemistry, too, and not just wet and dry analyses. He will need to know the theory of the diffraction of X-rays and how to determine the arrangement of atoms in a crystal. Therefore it seems to me that metallurgical education is of exactly the same nature as the training of an electrical engineer or a mechanical engineer. In other words, in addition to his practical training, that we have already heard of, he should have the pure theory, the pure science viewpoint on physics, chemistry and mathematics. I would be willing to have economics taught in the same way, too, that is study economics as an economist. In our business it does not make much difference whether a student goes to an electric engineering college or not. If he has had a good undergraduate course in pure physics and mathematics, we can make an electrical engineer out of him. If he has not the makings of an electrical engineer, no electrical engineering school in the country can make one out of him. It is similar with a metallurgist or metallographist; if he has the makings and has a good grounding in the fundamental

sciences, he can be given a start in the practical end and can make himself a metallographist or metallurgist.

It seems to me the fundamental thing is to take the youngster as he goes to college and get the idea into his head that he is not going to get education poured into him. He is going to go to school to *educate himself*, with a certain slight amount of assistance from the faculty, and education of himself consists primarily in getting the pure sciences as pure sciences in addition to the practical end. Some ten years from now such a man will not be a back number.

DR. ANCEL ST. JOHN: In a somewhat general discussion of the papers other than my own, I am first reminded of a very profound thought stated to my brother at one time when he was studying to be a professional musician, a teacher of music and possibly a performer on the piano. The head of the conservatory at which he was studying, said to him, when my brother asked when he might expect to graduate, "When I can assign you a new piece of music to study, you study it, you perform it and I cannot tell you any way to do it better. My entire object in life is to make myself unnecessary to my students."

It seems to me that this sums up the whole theory of education, whether metallurgical or whatever it may be, that the purpose of the teacher is to so teach the student to use his own mind that at the very earliest possible moment the teacher is no longer of any use to the student. He can do just as well on his own account. When that is done you can give him the degree and let him go out. Unfortunately, because of our present grading system, even if this has not been done, we must give him a degree and let him go out. Nevertheless, the dream is that the time should come when the test of education will be the ability of the student to think for himself and not the ability to repeat a number of things that someone else has done, or to remember all the values of space lattices for the different substances and the melting points of the different compositions of steel, and just where Ar_3 is no longer Ar_2. These are down in the book if you know which page of the book to look on, and if you do not, you take the book and page through it and find them. The ability to think is not found in books.

Along the same line, I believe, Professor Demorest likewise stated something very profound when he said, "The problem is merely a phase of the problem of teaching," or if I may paraphrase, "It is the problem of the selection of teachers." If your selection of teachers is sufficiently careful they may teach in the way Dr. Davey would have it done, or they may teach in the way Professor Demorest has suggested. It does not make much difference, because the right kind of a teacher, for instance, a professor of chemistry, when he happens to be teaching the section that is specializing in metallurgy, cannot fail to draw his special illustrations, that he is bound to use in his sectional teaching from the field of metallurgy. In other words, a professor of chemistry must be something of a metallurgist if he is going to teach chemistry to metallurgical students. Your professor of physics must be something of a metallurgist when he is teaching the section of metallurgy. And it is by encouraging a frame of mind of that sort among your

professors in the special lines that you will improve the quality of the metallurgical students you turn out.

CHAIRMAN HARDER: There are just a few things that I might mention. I think I am about half way between Dr. Hoyt and Professor Boylston on the phase rule. As soon as the work progresses to where something appears as a phase, I believe in calling it a phase, and if you have two phases and there is an equilibrium there, and it is best explained by the phase rule, that is the time I would introduce the phase rule.

As regards the impossibility of presenting the phase rule to certain classes of students, I have had the experience with one group of students which is probably different from the students which you have had. For example, we give metallography to the students in the college of dentistry. They take that work in their junior year, they do not elect it, they have to take it. We devote in that quarter about one-half of the time to the principles and we do not hesitate to introduce the phase rule, and furthermore we insist that they know something about it. As a means of determining their grasp of the subject we give them a collection of problems which involve the applications of the phase rule and the calculation of the per cent of the phases present, the discussion of the phase changes in the freezing of pure metals and of alloys. So that I think there should be really no difficulty in introducing the phase rule when it is the easiest way of explaining what happens. I do not see why it is necessary to handle this thing like the existence of Santa Claus, carry a fellow along believing one thing for a long time and then tell him, "Now that is explained in another way, we have not been telling you the whole truth." If the latest information which is available at the present time is well enough known, the teacher feels that that is the right thing, I should say, give it to the student the first time you give him any information on that subject.

The importance of the constitution diagrams has been discussed and we have had one experience which may not be new to any of you, but it may be, and it has been helpful to us and I am therefore going to discuss it.

We have found considerable difficulty in taking a constitution diagram and simply pointing to this and that line and telling the student that something happens between them, and that finally we have certain things. We have helped ourselves considerably on that subject by reproducing constitution diagrams, taking photomicrographs of the alloy structures, assembling those on one sheet, making them into a photograph or a slide, or into a film from which we can make blue prints. If we can have before the student at one and the same time the constitution diagram and a photomicrograph of the things we are talking about, it has helped us very materially to get across to the student the things that he should see.

The next point is that I do not believe too much in theoretical considerations unless they are accompanied by experimental work. If we talk about thermal analyses, the very next time we send a student to the laboratory we send him there to make a thermal analysis. If we talk about constitution diagrams, we will send him down to do some work on a constitution diagram. He may run only one cooling curve, but we want him to know how it is

obtained by actually working with it. When we talk about the microstructures on specimens, we send the student to the laboratory to find those forms. I believe that most people who are doing work in this field have adopted some similar scheme in which the laboratory work is designed to accompany the theoretical discussion. I know that our students could not get along in the theoretical discussion only, but they must have laboratory work designed to cover the particular field that has been discussed in the class and to supplement it.

H. M. BOYLSTON: I would like to ask Mr. Harder if these dental students are graduate students?

CHAIRMAN HARDER: No, they are undergraduates in the college of dentistry, and the prerequisite there is essentially a high school training. We teach it in the junior year.

QUESTION: What about the students in the college of dentistry?

CHAIRMAN HARDER: The general reputation of the students in the college of dentistry and outside of the college of dentistry is that they are not equivalent to the ordinary junior college student. They have not had the equivalent of that type of work. They have had more operating work in the field of dentistry.

H. M. BOYLSTON: Perhaps I did myself an injustice by saying that I generally taught the phase rule last, I did not quite mean that, because I had in mind a particular elementary course in which that comes last. Of course, we teach them more metallography and physical metallurgy later on, and by that time it comes about in the middle. But I wanted to get the impression across that I did not believe in beginning with the phase rule, because I find that the average student does not grasp it. He may learn the equations and the phase law and he may even know a certain number of the simple problems in connection with it, but I do not think he knows the significance of it until after he has been through other material.

DR. G. B. WATERHOUSE: Mr. Chairman and fellow members, there is really only one point I would like to make about this question of metallurgical education, but before I reach that I want to say how very much indebted all of us are for these papers that have been read this afternoon. It is a mighty hard field that the man has to meet in educating men in metallurgy. The general trend of the discussion has dealt with only one field of metallurgy. There are two very well defined fields, often spoken of as fire metallurgy and physical metallurgy. I think a much better way of thinking of them is Professor Howe's method, when some years ago he proposed the terms of product metallurgy and process metallurgy.

Process metallurgy has not been mentioned, at least in the discussion, and that is the field that most of our students enter. It is the field in which they receive the highest pecuniary rewards at the present time, and it is naturally the field that most appeals to many of them, and, of course, we have to fit the men to enter that field. Following that we must give the men at least some training in product metallurgy, or in what is often called physical metallurgy. I just wanted to bring that home to all of you men here, because it has been a little neglected, at least in the discussion.

You can readily see that our proposition of training metallurgists is a particularly hard one in the four years that we have to give to the student I am very much in sympathy with Professor Demorest that four years is enough, and not at all in agreement with the plan at Columbia University, that six years should be given. I think four years of the average man's life is enough time for the ordinary course in metallurgy.

When you also realize that our men are not going in the iron and steel metallurgy alone, many of them go into the field of copper metallurgy, many of them to the metallurgy of gold, metallurgy of aluminum and of zinc, etc., you can see there is a tremendous field for the man teaching metallurgy to compass.

J. P. BROWN: Gentlemen, there is one phase of metallurgical education that perhaps does not properly belong in this discussion, yet I would have been glad to have heard something on it. That is, not about the education of the metallurgical engineer or research man, but of what perhaps we call the practical man, the man at the fire; the man who does the work. I do not know whether there is any question as to the desirability of such an education. We have apparatus for ordinary control, etc., the red lights, or the "hump" when it is time to quench, still I do not believe there is any apparatus designed that entirely eliminates the human element in those processes, so we of the Philadelphia Chapter have thought there was a desirability to have such a course. We have had a night course at Temple University for several years, H. C. Knerr being director of that course at the present time, and I am wondering if you would be interested to have him give you an outline of it. I am very sympathetic towards such education.

When I became a steel treater, by accident, some 25 years ago, we heated dies to a cherry red, or a dark or light cherry red, and drew to a straw, a dark straw, or blue, or something like that. We would not have known a pyrometer if we had seen one. We did surprisingly well, considering what I find out now we did not know at that time. But it seems to me it is desirable to have those men know something about what they are doing, and I would like to have Mr. Knerr outline the course in the Philadelphia chapter for the benefit of these men, though it probably was not intended in this symposium.

H. C. KNERR: The Society is conducting, in a number of its chapters, evening courses for the practical man, such as we are trying to run in Philadelphia. The Chicago chapter was, I believe, the first to institute such a course, and the Philadelphia chapter second. I understand that there are now about ten chapters of the Society which are running some sort of a night school course for men who cannot avail themselves of a college education. I will tell you briefly what we are doing in Philadelphia, but first I would like to make a few comments on Dr. Hoyt's paper as it has a bearing on the program of our Philadelphia course.

Dr. Hoyt, it seems to me, has very well brought out the need for fundamental principles in metallurgical education. We might, perhaps, divide metallurgists into two classes, first, the research metallurgist whose laboratory and funds are supplied by a large and progressive organization, and who

is expected to do pioneer work in the realms of pure science; and second, the production metallurgist, whose job it is to keep things going in the shop and to supply the profits which support the research metallurgists.

There certainly is no question that the research man must have theory at his finger tips. The production metallurgist seldom has time to go into theory very extensively, or to keep pace with its rapid development, but he should have a clear understanding of the elementary scientific principles upon which his work is based. As he often is not a technically trained man, metallurgical education, to meet his needs, must be couched in simple terms, and must have direct practical application in his work.

Dr. Hoyt has laid great emphasis on the constitution diagram and the phase rule as the basis of metallurgical training. I think that might be interpreted in a little narrower sense perhaps than he intended. There are a number of other elementary principles which, it seems to me, are even more essential to the production metallurgist, especially to the man who is in charge of heat treating operations. He must have a general knowledge of what steel is, and how it is produced; he must know the use of the microscope and be able to recognize the various constituents in normal and heat treated steel, and the common impurities and defects of microscopic and macroscopic nature. He should have a clear grasp of the fundamentals of mechanical testing, and the physical characteristics of metals, and he should be well grounded in the principles of pyrometry. He should, of course, be taught the theoretical side of heat treatment and metallography, but he should also receive practical instruction in the application of those principles. Graduates of metallurgical colleges have applied for positions in the metallurgical department of our plant who could not explain the difference between a millivoltmeter and a potentiometer pyrometer. It seems to me that the more advanced theory is sometimes overemphasized in metallurgical training, to the detriment of these practical principles which every production metallurgist should know.

It is the general fundamental principles which in our night school course at Philadelphia, we are trying to give. This course is intended chiefly for the "practical" men, the men who make up the majority of the membership of our Society—men working in the factory, and at the fire. They come to the meetings of the chapter and say, "My gosh, this is all over our heads, it is high-brow stuff, we want something practical." We felt that the chapter might serve those men by establishing an evening course, and consequently we canvassed the various educational institutions to see if they would co-operate, and finally we received a very hearty response from Temple University.

An evening course was started which continues for 30 weeks, three nights a week. One night is a lecture period and the other two night are laboratory periods, when the men have the practical application of what they have been taught in the lectures. The lecture course can be taken by itself for those men who have not three nights a week to devote. The course is now starting its fourth season. It has been very well received, and we feel that we are helping along in one of the objects of the Society, namely, to promote

the science of the treatment of metals. I would like very much to hear from anyone else who is interested in such a course.

CHAIRMAN HARDER: I think before proceeding with the discussion, there is one thing that I should bring before this symposium, and that is whether in your opinion it is advisable to continue the metallurgical symposium next year. Your opinion at this time might be referred to the Executive Committee or Board of Directors of the American Society for Steel Treating, and it might be of considerable help to them in considering as to whether or not the symposium on metallurgical education should be continued another year.

J. P. BROWN: My opinion is it would be very desirable to have it continued and have the scope enlarged. The fact that the attendance is small is not a matter of discouragement at all, to my mind.

A. E. CAMERON: One question interested me particularly. I had hoped that in this discussion I would hear some discussion on the process, the study or the teaching of the processes of metallurgy. I might say first that I heartily agree with Dr. Hoyt that we should emphasize the fundamentals of mathematics, physics and chemistry. We have found that by the time we have done so, there is not much time left in the curriculum to give them any metallurgy other than process work. I would like to ask Dr. Hoyt just what portion of the under-graduate curriculum the metallurgical course should be given to the process, as against the theoretical end.

CHAIRMAN HARDER: Before too many leave, I would like to get an expression of opinion about continuing this symposium. If there is any further discussion, if there is someone who wants to make a recommendation in the form of a motion, we might have some motion of that character which we could refer to the Board of Directors.

A. E. CAMERON: May I ask if a symposium on that side of the subject of metallurgical education would be in order from the Society? I am not aware of whether it would or not.

CHAIRMAN HARDER: My opinion is that this symposium on metallurgical education is not limited in its field, that if it is desired to divide it into process metallurgy, or into metallurgy and metallography, all those subjects, everything that should come into the field of metallurgical education would properly belong in this symposium.

H. C. KNERR: I for one am very heartily in favor of having this symposium. I think the reason for the small attendance is because the convention is about over, and nearly every one is anxious to go home. I would like to offer a motion that the symposium be continued next year, and that consideration be given to having it at some time before the close of the convention. . . Motion is duly seconded.

CHAIRMAN HARDER: It is moved and seconded that we recommend the continuance of the symposium on metallurgical education, and that consideration be given to having that symposium sometime before the close of the meeting. . . Motion is unanimously carried.

Now we are ready to continue the discussion.

DR. S. L. HOYT: Professor Boylston brought up two points. One was

the emphasis on theory which I did not bring out in my talk, but which was brought out in the paper. I feel that the practical side of a student's education is very necessary, and that a considerable amount of time should be devoted to it, possibly more so than now, but that the time used for that part of the education should not come at the expense of training in fundamentals.

For instance, the student has some three months in the summer time in which he has not very much to do, so why not let him use, say, two months of that and work practically in the steel plants or smelters. At the same time a certain amount of time should be devoted to plant visitation and the study of processes, etc.

I think that a very definite attempt should be made to give the student that part of the training, but let us not make him sacrifice the four most valuable years in his whole training, or any major portion of those four years, to acquire something which he can acquire much better when he gets out.

H. M. BOYLSTON: Would you say that was true of laboratory work also?

DR. S. L. HOYT: Oh, no, I think laboratory work is a fundamental part of his training.

DR. G. B. WATERHOUSE: Even the plant visits, too?

DR. S. L. HOYT: No, I cannot conceive of a man getting the right training without the laboratory work.

DR. G. B. WATERHOUSE: Plant visits are part of the laboratory work, too.

DR. S. L. HOYT: Possibly plant visits, but not plant work.

DR. G. B. WATERHOUSE: But he cannot get in the plant work what he can get in plant visits while he is in college. That was the point Stoughton made.

DR. S. L. HOYT: Laboratory work and plant visitation and all that, are necessary.

H. M. BOYLSTON: That is all I wanted to point out.

DR. S. L. HOYT: Now as to phase rule, my remarks relate really to the professional metallurgist, to the one who is going to devote the rest of his life to the practice of metallurgy, and in that light it seems to me desirable to put the phase rule first. I am in agreement with Professor Harder that there is a certain technique of teaching which we would require as a skillful and easy approach to the phase rule, but as early as possible we should get the student acquainted with the phase rule and its doctrine. Now if you do not do that he very soon meets things which are not very clear to him.

Professor Boylston remarked that if you tried to teach him the phase rule too early you would give him something which he could not properly understand, and that, therefore, you should build up a foundation for the phase rule possibly after he learns such things as microstructure, thermal analysis, etc. It seems to me the thing really is the other way around, that he does not get the true appreciation of microstructure or of thermal analysis unless he understands the phase rule.

Mr. Knerr pointed out that I laid emphasis on teaching the principles of metallography rather than metallurgy or process metallurgy. It was pointed out in the paper that I have used the long course in metallography simply to illustrate the principles. If we are going to study the processes of metallurgy, there is a method of approach to them also, somewhat along the lines that I have suggested for metallography, so I think the remarks are adequately met by the paper.

H. C. KNERR: What is your definition of metallography?

DR. S. L. HOYT: My definition of metallography is the scientific study of the metals.

H. C. KNERR: The Bureau of Standards also use that definition, but is this not a broader meaning than the term can well carry? Other authorities have limited the definition to the study of the structure of metals, covering the broader science by the term "Physical Metallurgy."

DR. S. L. HOYT: The term metallography is well founded by practice, but I think metalology is a better term.

It has been suggested here that we do two things. Professor Honda made a suggestion that this Society, I believe, attempt to do something in the line of research students, or exchange research students between this country and Japan, and I personally made the recommendation that this Society do something in recognition of Professor Roozeboom's efforts. It seems to me that it would be a very nice thing for this assembled body to make some recommendation along these lines to the Board of Directors.

CHAIRMAN HARDER: I think it is in order to make a motion on either one of those subjects. Do you wish to make a motion, Dr. Hoyt, with reference to Professor Roozeboom?

DR. S. L. HOYT: Well, I would be glad to introduce a motion that, it is the sense of the Metallurgical Symposium, in view of Professor Roozeboom's contributions in the field of heat treatment, that the Board of Directors of the American Society for Steel Treating take such steps as they may consider appropriate to insure the association of Professor Roozeboom's name to the affairs of the Society.

DR. G. B. WATERHOUSE: In other words, you suggest it be referred to the Board of Directors. I will second that motion. Motion carried.

J. P. BROWN: Are you going to have Dr. Hoyt give the Executive Committee his views on that subject so they perhaps will be a little more enlightened than would come out of this motion?

CHAIRMAN HARDER: I think that might be a good idea.

I think if it is agreeable to those present at this Symposium, I shall ask Dr. Hoyt to see that this motion is called to the attention of the Board of Directors.

DR. G. B. WATERHOUSE: The other question seems to be such a broad one, this question of exchanging of professors between Japan and this country and exchanging of reserach students, I do not quite know whether we could take action—what are we, a committee meeting?

CHAIRMAN HARDER: I do not think so. I thing that we would be get-

ting rather out of our field if we did anything more than call the Directors' attention to this suggestion by Dr. Honda.

H. C. KNERR: I would like to offer a motion that this meeting is in sympathy with the suggestions made by Dr. Honda in the closing part of his paper and recommends it to the favorable attention of the Board of Directors.

CHAIRMAN HARDER: I am not sure that we are acting within our particular field when we make that recommendation. Motion seconded and carried.

CHAIRMAN HARDER: Is there anything further to come before this Symposium?

In closing, I wish to thank you people for the interest you have taken in this Symposium, and especially those who have contributed papers and taken part in the discussion.

B. F. SHEPHERD (Written discussion): The paper on "Metallurgical Education," by Dr. S. L. Hoyt, in the 1924 issue of August TRANSACTIONS strikes the right note in emphasizing the fundamentals to be used in training students to enter the metallurgical profession. The practical side of such training should and will come largely from actual works practice, but a proper balance between theory and practice is absolutely necessary in training as well as in later years.

The constitutional diagram is needed if we are to make much progress in the study of alloys, but it seems to me that Dr. Hoyt has laid too much emphasis upon the phase rule. This is especially evident when he asserts that the spread of the heat treatment of steel may be traced directly to Roozeboom's classical paper on the iron carbon consitution diagram. As a matter of fact, recent work has shown that Stansfield's diagram read at the same meeting of the British Iron and Steel Institute is practically correct, and that Roozeboom's interpretation of Roberts-Austens results are wrong. The phase rule seems to the writer to paraphrase in high brow language what we already know from a thorough study of the constitutional diagrams. Why complicate these further?

Jeffries and Archer are to be congratulated on their book entitled "The Science of Metals." If anyone has reduced the mystery connected with the heat treatment of steel, they have done it. Very little space is devoted to the phase rule, as their explanations are so clear and simple that anyone can understand them.

Dr. Hoyt also states that one of the leading British metallurgists criticized the methods used for teaching students microstructure at one of our leading metallurgical schools, and that he "agrees with the gentleman." "In this method each student is given a box of samples containing about fifty microsections labeled 'Cartridge Brass, etc.' and suggests that a preferable method would be to give the student a series of correlated specimens from one or more typical systems and to show him how the properties and structures vary with the composition and constitution. With the constitution diagram supplying the key, the subject matter is more easily retained

to become a real tool. The method employed at this school required the student to learn the microstructure of each technical alloy.''

I can hardly believe that Dr. Hoyt wishes us to feel that such a system is in vogue today in any of our leading metallurgical schools. The ''leading British metallurgist'' may have obtained a false surface impression which would have been completely corrected upon a closer examination, to his edification and benefit. It seems to me that no teacher of metallography would attempt to teach the subject without giving the students a thorough grounding in the thermal diagrams. This is the method used at Columbia, where I had the honor of studying under Dr. William Campbell, and I am sure it is followed in our other schools. At Columbia the laboratory work is used mainly to supplement the lectures which give plenty of ''potential energy.''

The type diagrams are first explained and then illustrated. For example, Type 1—for two metals completely soluble in all proportions in the solid state, is illustrated by samples of Monel metal, as cast, after hot rolling, after cold rolling, and faulty material. To illustrate the copper-zinc type diagram, a diffusion alloy is examined, showing alpha at the bottom, followed by alpha plus beta, then beta alone, while at the top is a mixture of beta and gamma. After this, samples of sheet brass, Muntz metal and manganese bronze are examined. Corrosion is shown by corroded admiralty and Muntz metal condenser tubes. In the same way the copper-tin diagram is illustrated by a diffusion alloy, each after a thorough explanation of the diagram.

The iron and steel series start with wrought iron, good and bad, then low carbon, rail and tool steel, white, mottled and grey cast iron and malleable iron. To show the effect of heat treatment, two samples of low carbon and two samples of tool steel are used. The samples of low carbon steel are first overheated to give them a coarse grain as in castings. They are about 1 inch long and ½ inch thick. One end is then held in the tongs while the other end is melted with an oxyacetylene torch. One sample is cooled in air while the other is quenched in water. The critical range occurs about the center of the sample. These two specimens show the effect of progressively higher temperatures on the structure and the difference between cooling in air and quenching. The same procedure is used on the samples of tool steel. It seems to me that if the students' time is to be conserved, such methods are necessary.

The majority of students who take metallography are not metallurgists, but engineers in general. They are more interested in studying faulty material and the causes of failure, the effect of cold work, annealing, etc., and they would soon lose interest if required to study a series of correlated specimens from one or more of the typical alloy systems and were expected to know all the others thereby. They would much rather study half a dozen typical babbitt metals and correlate the structure with ternary diagrams and physical properties than to cover, for example, the entire lead-tin-antimony diagram.

When it comes to teaching metallurgy I think our leading metallurgical schools are quite as up to date as any of the British.

THE HEAT TREATMENT OF AUTOMOBILE PARTS

By J. M. Watson

Abstract

The author of this paper briefly describes the methods and heating equipment used in one of our modern automobile factories. The furnaces described are of the automatic type especially designed to meet the requirements of the materials being heat treated. The furnaces are of the oil-fired, conveyor type.

Introduction

A FEW years ago weight in an automobile did not mean very much to the purchaser. Gasoline was cheap and tires could be purchased for a fairly low price. For those reasons manufacturers were content to use large sections of carbon steels or castings, relying upon the mass of the piece to withstand the shocks and wear rather than refinement of the material used. In those days alloy steels had not been highly developed and what heat treatment that was done, was usually carried on in a blacksmith shop, depending upon the heat colors for the proper quenching temperatures. Five or six thousand cars were a big year's production, and more individual attention could be given to each component.

Conditions at the present time are very much different. Gasoline is high, cars are being taxed on their weight, and economy of operation is a vital factor in the selling of automobiles. With the development of our modern alloy steels, it is possible to design parts where the stresses are taken care of and the piece materially reduced in weight and size. The use of alloy steels or the higher carbon steels calls for the utmost care in the heat treating processes. The very much increased production of cars, now nine or ten times as large as formerly, calls for mass production. Such being the case it has become necessary to design heat-treating departments that will give quality results on a quantity basis.

Stationary furnaces require a large amount of room, and a

A paper presented before the Boston Convention of the Society, September, 1924. The author, J. M. Watson, is metallurgical engineer with the Hupp Motor Car Corporation, Detroit.

large number of them are necessary to turn out the work. This in turn requires a large corps of men to handle the material, watch temperatures and burners, watch quenching mediums, etc. Formerly this type of equipment was in use in the plant with which the author is connected, but in order to turn out the necessary amount of work, two shifts of men were required practically all of the time.

A little over a year ago it was decided to build and equip a new heat treating department, with the sole idea of developing an equipment that would give the best results. It was decided that the equipment be automatic as far as possible. Much investigation of various equipments around the country, a study of catalogs and literature finally brought us to the conclusion that the only satisfactory solution to the problem was to build furnaces adapted to our own individual needs. All of the parts of the car that were subjected to heat treatment were first collected and furnace designs worked out accordingly.

Normalizing Furnace

One furnace is used exclusively for normalizing forgings and annealing cast iron parts. This furnace is equipped with a continuous pan conveyor. (Fig. 1.) These pans are made of a special heat resisting alloy and are so designed that they hook together on the bottom. They have been grooved on the bottom so as to fit skid bars on the hearth of the furnace over which the conveyor slides. One point in the construction of this furnace deserves special attention. These conveyor pans go through the furnace under compression instead of being pulled through. They are pushed by two parallel hooks mounted on a shaft which grab projections on the bottom of the pan and push them forward at each stroke. The shaft to which the hooks are attached is located at the end of an arm which is rocked backward and forward by a motor driven crank. At the conclusion of the forward stroke it is necessary to hold the hooks up against the bottom of the pan conveyor so they will engage the next pan at the proper moment. This is done by parallel floating levers pivoted on another shaft on the rocker arm. A counter weight on the lower end of each lever holds the upper end against the bottom of the hook. The upper end has a double flange which engages the hook-arm with-

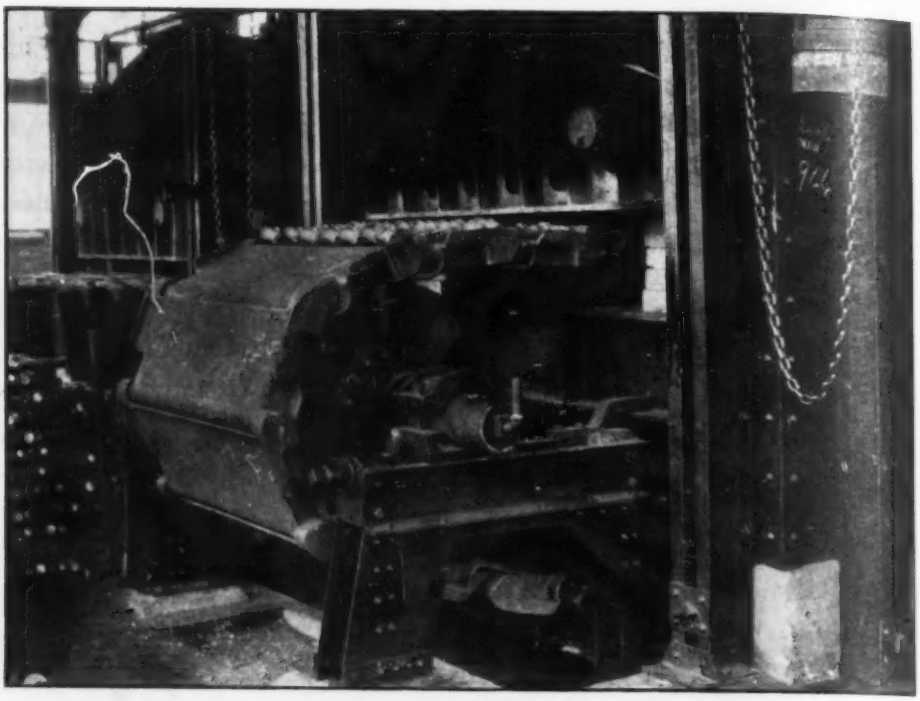


Fig. 1—Normalizing and Annealing Furnace used for Small Parts and Castings. This Photograph Shows the Construction of the Hearth and Interlocking Plates which are Pushed through the Furnace by Rocker Arms.

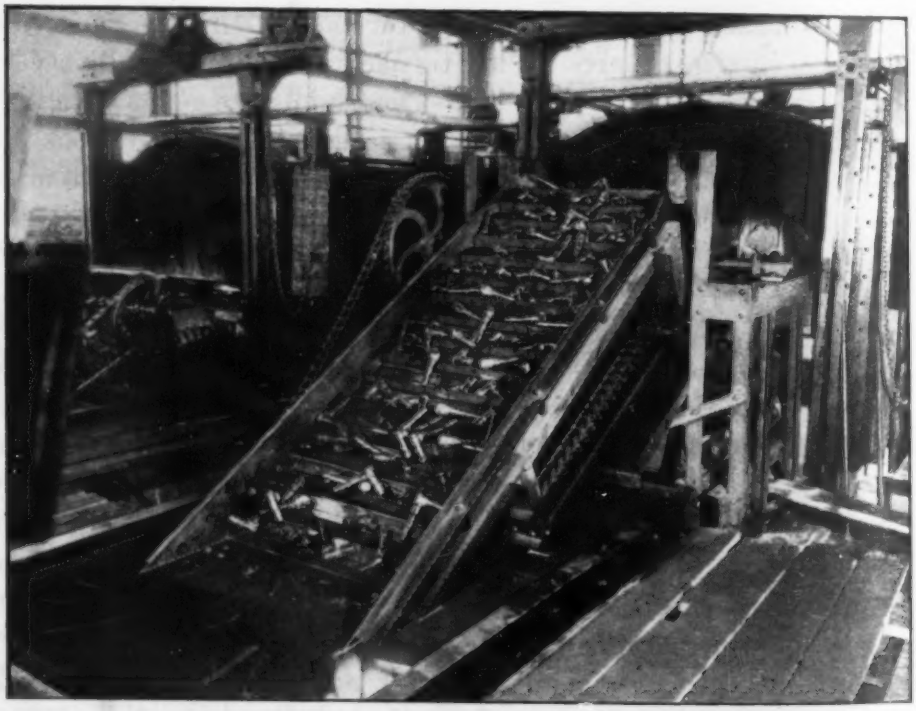


Fig. 2—Furnace Used in the Heat Treating of Small Parts. Showing Pan Conveyor used for Transferring Parts from the Quenching Bath to the Tempering Furnace.

out interfering with its forward or backward movement. There are counter-weighted doors at each end of the furnace which are kept open just enough to clear the pieces in the furnace. All of the parts are carefully laid on the pans and no piling of material is permitted. At the discharge end of the furnace the parts fall into trucks and are carried to the hardening furnace. The inside dimensions of the furnace are five feet wide by eighteen feet long.

Hardening Furnace for Small Parts

The second unit of this equipment is the furnace for small parts, such as steering knuckles, equalizer pivots, drive shafts, etc. This unit, shown in Fig. 2, consists of two furnaces, one for the hardening heat and the other for the drawing heat. These furnaces are of the same design and dimensions as the normalizing furnace just described with one or two changes. At the discharge end of the hardening furnace the material is dropped into a bath of quenching oil. The furnace end is so covered that the parts do not come in contact with the outside air at all. This prevents any lowering of the heat of the part and does away with a great deal of scaling.

The parts are picked out of the oil bath by a pan conveyor which has perforations in the bottom of the pans to allow the oil to drain off. They are deposited on the conveyor of the draw furnace, but of course are piled up. This is a condition that tends to promote non-uniformity, so in order to level the forgings out, a heavy piece of sheet iron is hung directly over the door. This has enough weight and spring so the knuckles, etc., are smoothed out and go through the furnace, thus receiving a uniform temper.

Hardening Front Axles

The unit for heat-treating front axle I-beams is of an entirely different construction. (Fig. 3.) The forgings are carried through the furnace on a moving hearth which has a forward stroke of six inches. As the hearth is raised up by cams located in the bottom of the furnace it picks up the I-beams which are resting on piers. These are carried forward, and as the hearth goes on its downward stroke they come to rest on the piers again. This process is continuous, the piers extending the whole length of the furnace. The hearth is operated by two sets of cams which come

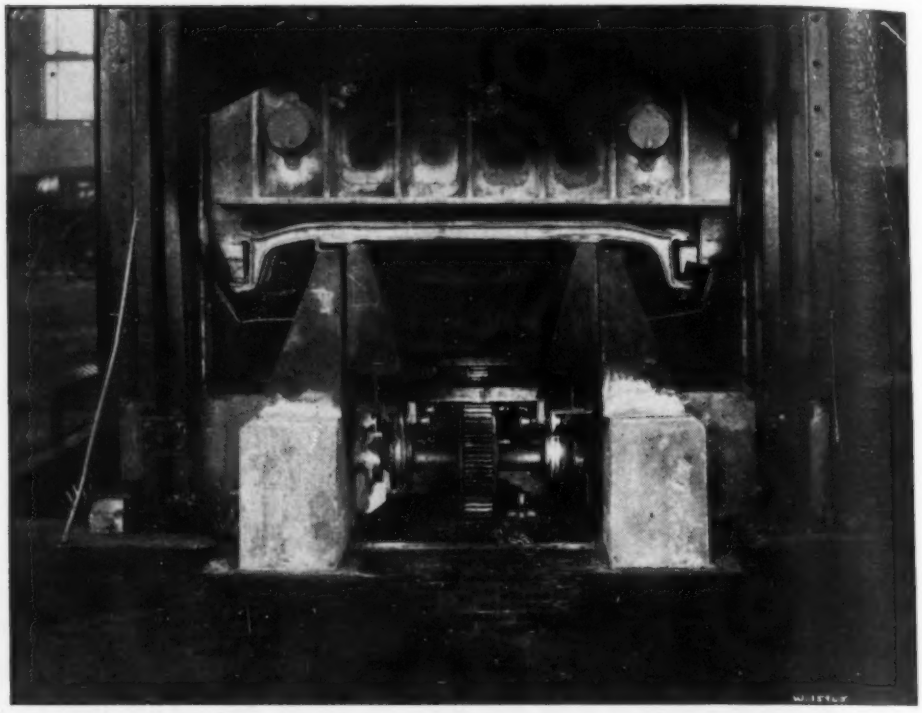


Fig. 3—Charging End of Hardening Furnace used in the Heat Treatment of Front Axles. This Furnace is Provided with a Movable Hearth.

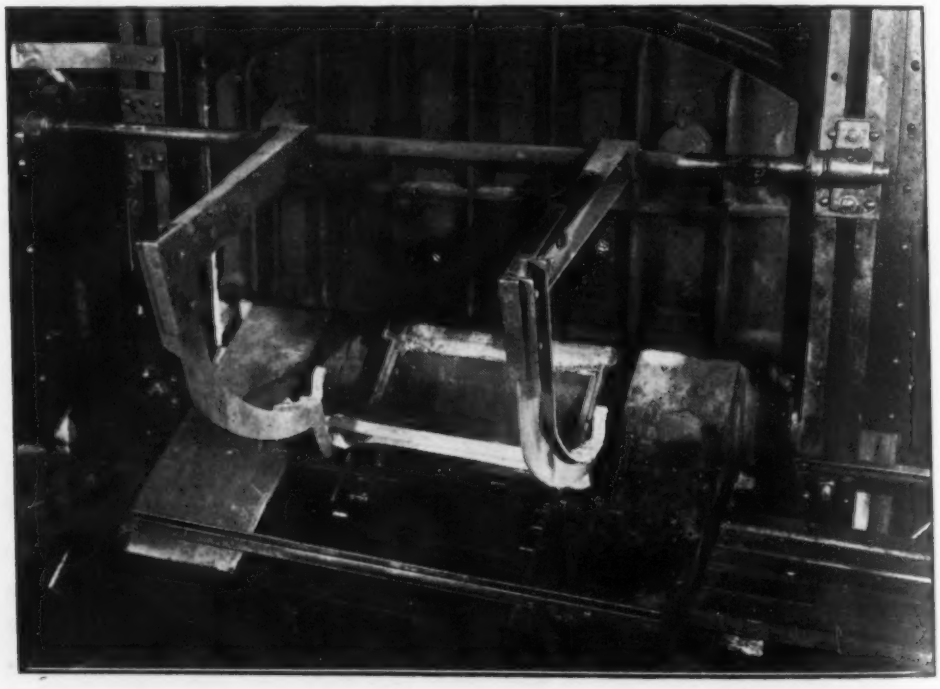


Fig. 4—Discharge End of Hardening Furnace used for the Heat Treatment of Front Axles. The Automatic Quenching Device is Clearly Shown.

in contact with saddles bolted to the bottom of the hearth. There are four cams, two at each end of the furnace, which are operated by gears and which in turn are driven by a variable speed motor.

When the forgings reach the discharge end of the furnace, Fig. 4, they drop onto a pair of counter balanced fingers which allows them to drop into the oil in a level position, thus preventing excessive warpage. They drop onto a chain conveyor equipped with fingers so spaced that they synchronize with the movement of the hardening unit. They are picked out of the oil and conveyed to the draw furnace of this unit. (Fig. 5.) This furnace is equipped with a radial blade conveyor made by riveting fan-like blades to a link chain. (Fig. 6.) These blades are so staggered that they overlap and form an endless belt. At the discharge end of this furnace the axles are dropped on trucks.

The furnaces are each equipped with four burners, two on each side, staggered so as to give uniform heating. Fuel-oil is supplied under pressure from storage tanks placed under the platform at the end of the building. A supply of 30,000 gallons is provided, and each tank is equipped with a steam coil to prevent the oil from becoming sluggish in cold weather.

There are two tanks provided for the quenching oil; a large 15,000 gallon tank for the main storage and a smaller one holding 4,000 gallons in the building. This latter oil is kept in constant circulation by pumps. It enters the quenching tanks directly under the discharge end of the hardening furnaces, so that the work being treated comes in contact with cold oil. The oil then passes out and is carried back where it goes through a series of filters to remove any scale or dirt that may have collected. It then passes over a series of baffle plates and pipes through which cold water is continually passing. This water is in turn cooled by being pumped through a spray pond. The results obtained in heat treating steel depend a great deal on the temperature of the quenching oil and by the method just described a maximum of 110 degrees Fahr. is maintained.

Temperature Control

Another vital part in good heat treatment is temperature control. These furnaces are each equipped with two thermocouples, one about two-thirds the length of the furnace where the parts

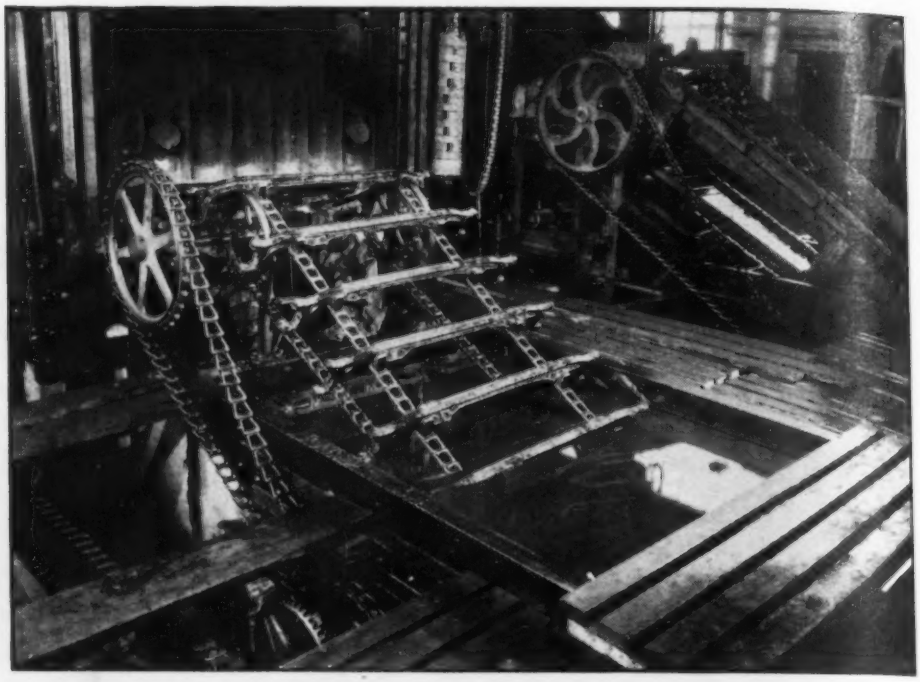


Fig. 5—Tempering Furnace for the Tempering of Front Axles. Showing the Automatic Conveyor used in Transferring the Axles from the Quenching Tank to the Furnace.

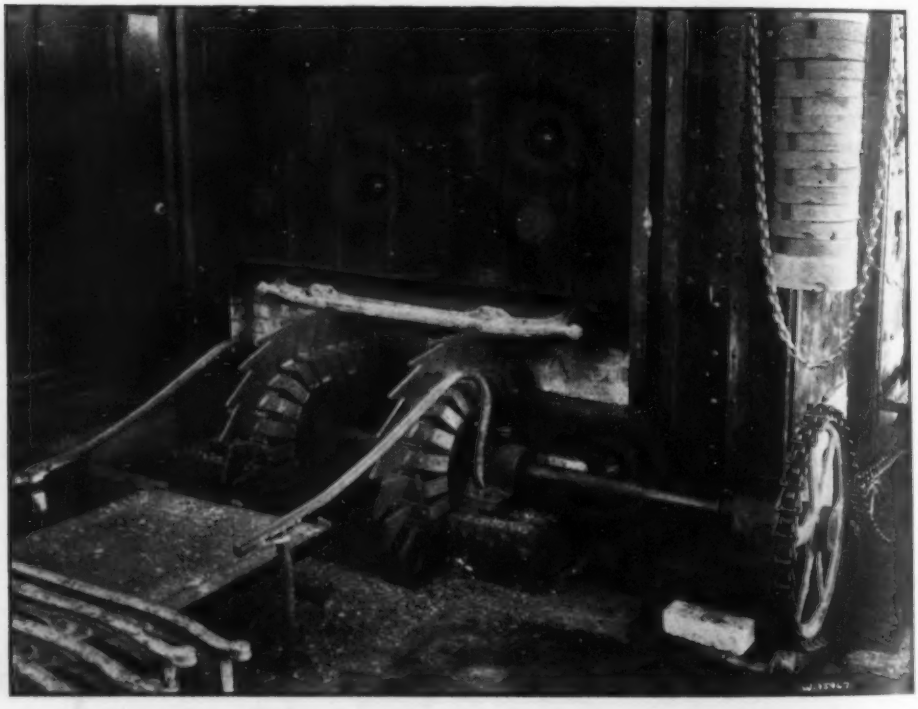


Fig. 6—Discharge End of Front Axle Tempering Furnace. Showing the Construction of the Radial Blade Conveyor used in Moving the Axles through the Furnace.

reach their maximum temperature and the other at the discharge end to make sure that the correct temperature has been maintained. On the side of each furnace has been placed a deviation indicator to show the number of degrees the temperature is varying from that desired. Over the furnace are hung signal lights to show the condition of the furnace: if a red light shows, the temperature is too high; if blue, the temperature is too low; and a white light shows the heat is correct. These lights switch between the two thermocouples once a minute so the temperature of the critical zone of the furnace is known at all times. Recording instruments are kept in the foreman's office so that a permanent record is kept of all operations.

Following the heat treating processes all the vital parts, steering knuckles, steering knuckle arms, I-beams, drive shafts, etc., are given one hundred per cent Brinell inspection.

Conclusion

The object of this paper is to bring before you the care that is being taken to produce parts made of steel that will stand up under severe strains, and to impress upon you that the metallurgical profession should at all times strive to improve ways and means of heat treating automobile parts with a view of longer life to the car, and safety to the owner.

Discussion of Mr. Watson's Paper

Chairman White: I am sure you will all agree that this is a splendid set of films and that the general tendency of the times seems to be toward what we might speak of as mechanical heat treatment. I am just going to ask that we conduct this meeting in the same manner as we have conducted other meetings, and those who have questions to ask or who wish to take part in the discussion will kindly do so.

J. F. Culp, Jr.: Do you anneal all your cast iron parts?

J. M. Watson: Everything except the transmission case. Of course, we do not anneal the cylinder block because that is too large. We are seriously considering it inasmuch as we believe we will get more uniform hardness all the way through if we do. So far as I have been able to see, the temperature that we anneal cast iron at, which is around 1250 degrees Fahr., does not have any effect upon the microscopic structure of the iron. Under the microscope it looks just about the same as it does before it goes through the furnace. I think you have to raise cast iron up to 1350 or 1400 degrees Fahr. before any growth of graphite is apparent.

A MEMBER: I have had a problem along that line and I have found by experiment that if the temperature is raised to about 1400 or 1425 degrees Fahr., growth is started, and if the temperature is increased the growth increases considerably, but under these conditions I have never experienced any trouble.

H. B. NORTHRUP: I would like to ask Mr. Watson what concentration of cyanide is carried in the bath used for case carburizing by the cyanide method. What percentage of NaCn is used?

J. M. WATSON: To be frank with you, I do not know.

H. B. NORTHRUP: Do you use it diluted?

J. M. WATSON: Yes, we use the diluted material, but just how much, I do not know.

R. W. STAMP: I would like to ask you how you handle your gears after re-heating; wire brush them or sand blast them?

J. M. WATSON: We do not manufacture our own transmission gears. Those are all purchased outside. I will say though that the gears are all sand blasted before they come in.

R. W. STAMP: A good many people are wire brushing now and I am interested to know what methods you use for removing any scale?

J. M. WATSON: We have our gears sand blasted.

CHAIRMAN WHITE: Mr. Ryan would like to add something.

F. J. RYAN: I believe there are some very important items in this furnace construction that ought to be of interest to you men that may have been overlooked by Mr. Watson, maybe in the sense of bashfulness, because they do bear fundamentally upon our future progress of furnace building.

When this furnace was first thought of, the Hupp Motor Car Corporation in talking it over with us asked for suggestions; suggestions that would give them possibly the latest possible ideas that might be evolved in heat treating in the furnace structure. The question of the newness was, of course, gone into and we finally, in working up certain of these designs, presented them to Mr. Watson, who was responsible for the negotiation. These furnaces involve an entirely new principle in furnace construction. In the one conveyor furnace that you saw there are some $6,000 to $7,000 worth of alloy castings.

As you know, practically all pan type furnaces before have been of the form where the pan was pushed through and discharged with the material into the oil. This method meant both a high cost of treating and also a high cost of handling.

Now these pans, as you see, do not enter the oil at all, they return; they are all interlocked; they are not on a conveyor within the furnace, they are on a rail and they are pushed through practically counter-balancing themselves. It takes, in the total drive of that operation, less than one horse power to drive the total equipment.

If there are any particular mechanical features that you are interested in, I would be very glad indeed to tell you about them, but I do not think there are, because, really, the entire operation is simplicity in itself. It has very

few gears, the drive is simple, there is nothing complicated, nothing elaborate to get out of order, and it is all open.

J. M. WATSON: I might say that if anybody ever gets within calling distance of our plant, which is in Jackson, Michigan, about 70 miles west of Detroit, all you have to do is just go to the front door of our branch there and say you would like to see the heat treating plant, and they will take you out and show you anything you want to see and tell you anything you want to know about. The invitation is wide open for anybody who is interested.

CHAIRMAN WHITE: Have we any other questions? We have here, I think, a very important matter. I am wondering if you would permit me just to ask these gentlemen one question, and that is this. Last summer it was my privilege to visit a number of plants and I found a good deal of progress being made with reference to scientific heat treatment, but there was very little apparent progress in the equipment used for carburizing. That operation in most cases seemed to be carried on as it had been carried on for the past five or ten years. The progress in the other lines of heat treatment was outstanding, but the progress in the carburizing lines did not seem to be undergoing the same rate of change. I would like to ask Mr. Watson what progress has been made in this particular line of heat treatment.

J. M. WATSON: I might say, Colonel White, that so far as I know the most recent development along carburizing lines is in the rotary furnaces. We have not gone into that ourselves, because, as I say, we do very little carburizing. We wanted to get the other branch of our work under control before we dabbled with case carburizing.

F. J. RYAN: I think probably the answer to that question rests within the group of men here rather than the furnace builder. The furnace builder can only actually function after the metallurgist has established his case, and in nearly every problem that we have submitted, innumerable types of new developments, they all fall flat because of the fact of inflexibility to the particular operation desired. Small production does not warrant the automatic features. In a large production such a very wide range of treatments are required that the usual result is the batch type furnace. A furnace of an automatic nature is inherently a quantity production instrument, and if you have not a quantity production it is really expensive and useless to attempt to use an automatic furnace.

W. D. FULLER: Rotary furnaces that you just referred to are batch type furnaces; they are not continuous, and they are made in small sizes as well as large, and production therefore is taken care of.

F. J. RYAN: But the trouble is, it is just a question of whether a rotary furnace is actually a batch furnace. Of course, you put a certain amount in, and it is a question whether you are accomplishing anything by doing it. If you have half a dozen rotary furnaces in a line, it is purely a matter of man labor of accomplishing that result. You take furnaces that have been described in this issue for carburizing, they only involve principles of mechanical work. They still need keenness of supervision in order to produce the results. While we have the principles to help the men, it all comes back to the motorman and the power to make it run. I think it is a

question of the furnace design, more along the line of standardized specifications of a rigid nature, which is then put up to the furnace engineer to begin from that point to meet that condition.

W. D. FULLER: Rotary furnaces do take less labor. That has been proven. It is proven every day in the week, and they certainly do not need a higher class of labor to run them, so I think that would mark a step in advance in carburizing.

A MEMBER: One of the points in favor of a rotary carburizing furnace is along the lines of better heating that everybody is looking for. With a rotary carburizing furnace the carburizing box is hot from the start, so you do not have to heat the container, and the work is rotated so the case is generally much more uniform, particularly on short periods, because there is not the time lag between the pieces at the outside of the box and on the inside.

A MEMBER: In the annealing operation of the cast iron castings how long are the castings held at temperature?

J. M. WATSON: They go into the furnace cold. The furnace is about 18 feet long on the inside, and they are held at the annealing temperature about 20 to 25 minutes. Some of the castings have heavy sections.

J. VAN DER VORN: I would like to hear a little fuller explanation regarding the agitation of the oil in keeping it at the proper temperature, where you submerge your pots.

J. M. WATSON: As I say, we have 4,000 gallons of oil that is in constant circulation all the time. The tanks are so arranged that the cold oil comes in immediately at the quench end of the furnace, so that when the heated material comes off the conveyors it drops into the coldest oil. That oil is circulating all the time; being operated by a pressure pump system, so that the oil is not stationary and has no chance to get hot. We have such a large capacity going through that we have no trouble, even in the hottest weather this summer, the maximum temperature we got on that oil was 110 degrees Fahrenheit.

CHAIRMAN WHITE: Do you have some other questions? I think we have a wonderful opportunity here to ask questions. Those of us who are close to Detroit realize that the equipment at Jackson at the Hupp Motor Car Corporation is one of the very best that we have.

F. J. RYAN: There is one other point that I think would be of interest, and that is the matter of the oil. Some of you may use it, but perhaps the rest do not. Instead of taking the cooling system to the oil we bring the oil to the cooling system. As a result, a higher percentage of control is obtained, and by the speed of operation of the pump we can control any temperature of that oil that is necessary, or that is desired. That spray pond is just not incidental, it was all designed with the whole equipment. The cold water passes through the coils and the oil is passed in cataract form over those coils, so by either grading the speed of the oil or of the water you can control the temperature of the oil at any desired degree; and then by a system of leverage it is either by-passed or immediately pumped back into storage. Another point that Mr. Watson did not touch on is the fact that these fur-

naces are designed to go up to 1850 degrees Fahr. The entire control throughout the whole equipment is based upon that same condition.

CHAIRMAN WHITE: I am wondering if Mr. Watson or Mr. Ryan can answer the reduction in the number of heat treatments as the result of automatic feeding and discharging.

J. M. WATSON: I cannot give it to you in percentages, but it is very much lower than it ever was under the batch furnace system, and we not only get fewer rejections, but we get much more uniform results all the way through the entire batch of material that goes through. Even in the tempering furnaces there is absolutely no piling up of material at all. As the steering knuckles, for instance, come out of the oil, they are carried up in this pan conveyor and dumped on the hearth of the tempering furnace. Of course, they go down in a heap. In order to flatten those out a heavy steel plate is hung in front of the door of the furnace, with a spring on it with enough tension in that spring so that as this pile of knuckles goes up against the steel plate it just swings out and scrapes the knuckles down level, so they are only going through one high. There is no piling up of any material at all which, to my notion, is one of the greatest things to develop uniformity in your final product.

CHAIRMAN WHITE: Any further questions?

QUESTION: In the normalizing process on the steering knuckles, are they cooled in the furnace or where?

J. M. WATSON: They fall off into the truck and are cooled in the truck.

AN ASSUMPTION AS TO THE CAUSE OF THE CHANGE OF BODY-CENTERED ALPHA-IRON TO FACE-CENTERED GAMMA-IRON

By E. J. Janitzky

Abstract

The author of this paper offers a mathematical explanation of the causes for the change of iron, when heated, from a face-centered to a body-centered orientation.

X-RAY crystal analysis reveals the arrangement of atoms in space. In iron, for instance, it distinguishes, according to temperature, two arrangements which although cubic are body-centered for the alpha-iron and face-centered for the gamma-iron. In this paper it is endeavored to present a possible explanation of the causes for the change from the body-centered to the face-centered cubic arrangement.

Between the atoms in the space lattice are attracting forces, acting however, different from gravitation, as they are only effective over very small distances. Besides this, the atoms are in constant movement, which is proportional to the absolute temperature. The movements of the atoms in a crystal are limited, or otherwise a return to the original space lattice would be impossible and the crystalline state would disappear. The same may be assumed of the attractive forces in a given gravitational field.

Laying a plane through the area of largest atomic density in a body-centered and face-centered cubic unit of the same dimensions, (Fig. 1) one is aware that the attraction distance $\frac{D}{2}$ of a body-centered atom, in regard to the opposite corner atom, is larger than the attraction distance $\frac{d}{2}$ of a face-centered atom, or mathematically expressed, when a denotes the side—

$$\frac{D}{2} = \frac{a}{2}\sqrt{3}$$

$$\frac{d}{2} = \frac{a}{2}\sqrt{2}$$

The author of this paper, E. J. Janitzky, is metallurgical engineer with the Illinois Steel Co., South Chicago, Illinois.

It will also be noted that the section through the attraction field of the body-centered atom is a rectangle, whereas that of the face-centered atom is a square.

With an increase in volume of the cubic unit by thermal expansion, the attraction distance $\frac{D}{2}$ or R will reach a magnitude where it will be unable to hold equilibrium in its attraction field

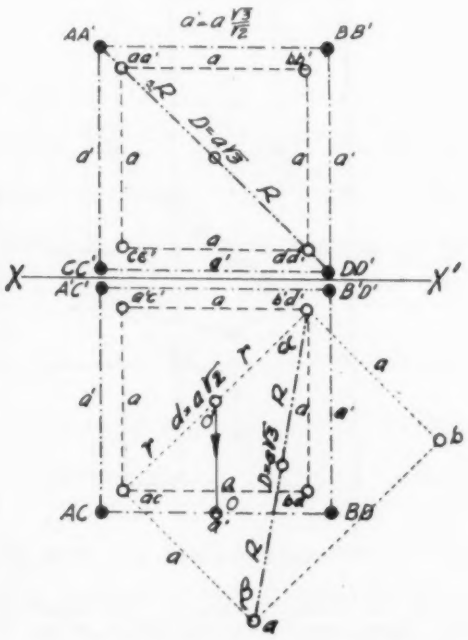


Fig. 1—Mathematical Calculations of Attraction Distances of Atoms in Body-Centered and Face-Centered Cubic Units of the Same Dimensions.

and the body-centered atom will naturally tend to locate itself in another field. The logical field of attraction to enter is given as a center atom in a face of a cube, as in this position there is an increase in volume of the cubic unit possible without an increase of the attraction distance between center and corner atoms in the field of largest atomic density. (Fig. 1.) The five adjoining close-packed body-centered cubes will for the same reason dislocate its body-centered atoms and supply them to the five remaining faces of the cube under consideration and form a complete face-centered cubic unit.

The perspective reproduction, Fig. 2, demonstrates the supposed mechanism of transformation of a body-centered to a face-

centered cube. The front cube was omitted as it does not take part directly in the atomic transformation but obtains a joint face-centered atom from the cube under consideration and hence will require four atoms to form a complete face-centered cube.

Considering the transformation from a body-centered to a face-centered cube mathematically (Fig. 1), let us denote at that

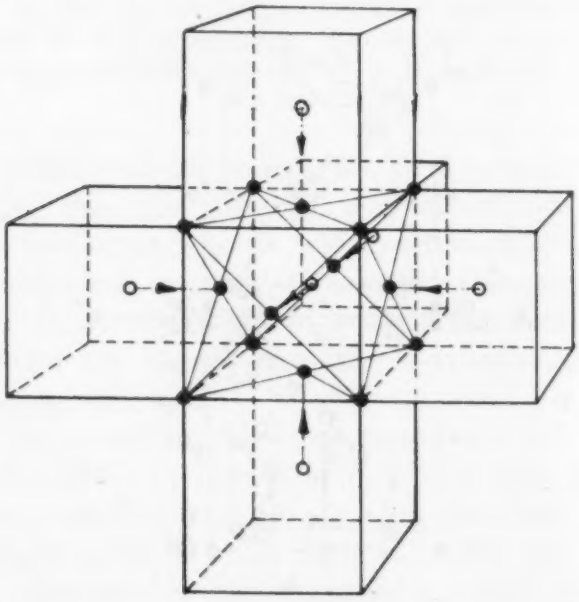


Fig. 2—Perspective Reproduction Demonstrating the Supposed Mechanism of Transformation of a Body-Centered to a Face-Centered Cube.

moment the side of the body-centered cube as a. Hence the face diagonal will be—

$$d = a\sqrt{2}$$

and the diagonal of the cube—

$$D = a\sqrt{3}$$

The magnitude of the attraction distance is therefore—

$$R = \frac{D}{2} = \frac{a}{2}\sqrt{3}$$

The angle α and β of the attraction radius or distance in the

field of largest atomic density in a body-centered cube, will be—

$$\alpha = \tan \alpha = \frac{a}{a\sqrt{2}} = \frac{1}{\sqrt{2}} = 35^\circ\ 18'; \text{ and } \beta = (90^\circ - 35^\circ\ 18')$$

If, as assumed, the body-centered atom will enter the attraction field of a face of the cube, it is obvious that the attraction radius will change its angles in its new position to 45° and become diagonally located in a square with a side a′—

$$a' = a\frac{\sqrt{3}}{\sqrt{2}}$$

Let us substitute in the above formula for a, the value of a side of a body-centered cube in Angstrom units—

$$(1\text{Å} = 10^{-8} \text{ cm.}) = 2.91 \text{ Å}$$

Hence, we will obtain for a′, which represents the side of a face-centered cube—

$$a' = 2.91\frac{\sqrt{3}}{\sqrt{2}} = 3.57 \text{ Å}$$

The actual available measurements* are given as 3.61 Å, which therefore gives a difference of 0.04 Å between calculated and actual values.

It is apparent that the face-centered cube will be larger than the original body-centered cube. However, the amount of cubes formed will be less as atoms will be consumed in building up face-centered cubes. A temporary, coincident increase and decrease of volume will take place during this atomic metamorphosis.

In concluding, the writer wishes to state that the calculated and actual values approach each other within very close limits, and one would be led to the conclusion that the tendency in the change of body-centered to face-centered cubes is in accordance with the transformation theory outlined.

*Figures as given by Westgren.

NOTES FROM THE U. S. BUREAU OF STANDARDS

High Temperature Properties of Metals

In connection with the Bureau's investigation of the properties of metals at high temperatures, which has been mentioned in several previous numbers of the Bulletin, another automatic temperature controller has been installed and put in working order, so that the two units for long time testing are now complete, have been calibrated, and tests are being carried out.

Preliminary tests have been made at temperatures of 550 and 800 degrees Fahr. on low carbon hot rolled steel at loads ranging from 10,000 lbs. sq. in. below the proportional limit, to 20,000 lbs. sq. in. above it at lengths of time varying from one to seventy-two hours depending upon the load and temperature chosen. These tests are still in progress so that no conclusions have been drawn.

Physical Constants of Pure Zinc

Twenty specimens of pure zinc have been cast by the Bureau and machined into tensile samples. These samples have been annealed at 150 degrees Cent. to relieve strains from casting. An electrically-heated oil bath furnace of improved design has been set up in the testing machine, and several pure zinc specimens have been pulled. Several tests will be made over the range of temperature possible, and additional tests will then be made more frequently in the range of supposed allotropic change. Plans include tests on zinc quenched from different temperatures; the taking of cooling curves; and an X-ray examination at elevated temperatures.

Gases in Sheet Steel for Welding

Manufacturers of Oxy-acetylene welded sheet steel products, (tubes, barrels, etc.) encounter certain lots of sheet which give unsatisfactory welds apparently on account of the evolution of gas as the molten weld metal freezes. Samples of satisfactory and unsatisfactory sheet steel have been submitted to the Bureau by a tube manufacturer, and similar samples have been promised by manufacturers of welded steel barrels. One manufacturer has stated that there is some evidence that an aluminum treated steel is quite liable to give poor welding sheet. Analyses are in progress to determine if any difference exists in the gas content of these two grades of welding steels.

Investigation of the Wearing Properties of Steel

Several spherical specimens have been prepared, and as soon as they are heat treated and the surfaces are finished they will be tested in a small rubber-lined ball mill with approximately the same abrasive as was used in the lapping tests on these same steels. The tests should prove definitely whether the ball mill is suitable for wear testing of gage steels.

Information from Technical News Bulletin No. 91, published by the Department of Commerce, Bureau of Standards, Washington.

Influence of Sulphur, Oxygen, Copper, and Manganese on the Red-Shortness of Iron

This investigation was undertaken to throw light on some disputed matters as to the elements in iron which cause it to be brittle when worked on a forge or otherwise above a red heat. Sulphur is generally admitted to be a cause of this defect, but data as to the minimum percentage of this element necessary before red-shortness disappears are rather meager. Oxygen has been considered by many metallurgists to be as important in this regard as sulphur. The opinions on effect of copper are quite variable. Manganese is conceded generally to be a corrective for the red-shortness caused by sulphur, and is thought by many to prevent or help prevent the red-shortness supposed to be caused by oxygen. Data as to the amounts of manganese to be used are given in the literature, but are in some cases contradictory.

Much of the discrepancy in views regarding effects of some of these elements is due to studies having been made on commercial steels in which it is difficult to insure that the element or elements studied are the only important ones present. This investigation has, therefore, been made with electrolytic iron or commercially pure iron as raw material. The melts were small (900g. approximately) and made under fairly good control in carbon helix vacuum furnaces or in a high-frequency induction furnace under air. The copper added was over 99.9 per cent pure and the manganese over 98 per cent. The carbon content of the samples in most cases did not exceed 0.60 per cent. The ingots were forged to one-half inch bars and then tested for red-shortness by bending back and forth over a blacksmith's anvil in a temperature range of 1,100 to 500 degrees Cent. Samples classed as free from red-shortness were those which stood such a test without breaking.

The conclusions of this study are:

1. Sulphur is the principal element responsible for red-shortness. In order to prevent red-shortness in iron not more than 0.01 per cent sulphur should be present.

2. Oxygen in amounts up to 0.20 per cent does not cause red-shortness in pure iron if the sulphur is below 0.01 per cent.

3. Manganese may prevent red-shortness in iron when present to the extent of three times the sulphur percentage if the oxygen percentage is not above 0.04 per cent.

4. The presence of considerable amounts of oxygen in irons (0.10 per cent and above) tends to reduce the efficiency of manganese in preventing red-shortness. The hypothesis is advanced that this is because some of the manganese reported in such irons is present as oxide.

5. Copper (0.05 to 0.5 per cent) is of minor importance in its effect on red-shortness of pure iron, but in some of the specimens described in this paper it tended to decrease the red-shortness.

A complete description of this investigation will be found in Technologic Paper, No. 261, copies of which may be obtained from the Superintendent of Documents at 10 cents apiece.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

QUESTIONS

QUESTION NO. 138. *Is the electrolytic pickling process being used to show up defects in steel bars? If so, how does it compare with the regular pickling processes?*

QUESTION NO. 139. *What is fibre, as related to forgings?*

QUESTION NO. 140. *Can fibre be removed by heat treatment? How and to what extent?*

QUESTION NO. 141. *Does fibre exist in castings which have been subjected to mechanical working?*

ANSWERS TO QUESTIONS

QUESTION NO. 120. *How does the carbon content affect the secondary hardness of high speed steels?*

QUESTION NO. 130. *Is there any advantage in using notched-bar impact tests in the inspection of annealed tool steel bar stock? What does such a test show?*

ANSWER. In the inspection of annealed tool steel the notch bar impact test would be an advantage in checking up on the annealing operation.

If the steel were in a coarse grained condition with cementitic boundaries caused from overheating, or if the original structure were not completely broken up, the impact test would be low.

It would be necessary to have a set of average impact results obtained from steel considered satisfactory, for each specific grade of tool steel being inspected, in order that a comparison might be made.

QUESTION NO. 131. *Given an alloy of the brass or bronze type, in which there are no critical transformation points, suppose that through carelessness the metal has been overheated, producing an undesirably coarse crystalline structure, is it possible to refine the grain without remelting or mechanical work?*

ANSWER. From all the information which we have been able to collect on this subject it appears that there are no methods of heat treatment which

can be used to restore coarse grained structures in brasses or bronzes resulting from over-heating.

QUESTION NO. 133. ***In annealing a carbon tool steel of*** 1.30 ***to*** 1.40 *per cent carbon, are there any ill effects to the steel in allowing it to soak for an hour or more at* 30 *to* 40 ***degrees Fahr. above the critical point?***

ANSWER. When steel is heated through its critical point, the grains immediately begin to grow. This growth will continue as long as the steel is held above the critical point. When allowed to cool slowly the grains will be reduced in size somewhat while passing back through the critical range, but after the transformation has taken place the grains remain the same size. For this reason it is not advisable to hold steel above its critical point longer than is necessary to obtain the results sought.

Surface decarburization may also be a result of such heating.

QUESTION NO. 134. ***What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?***

QUESTION NO. 135. ***From what material should the gears and pinions be made to be used in a galvanizing bath, that is, operated under molten zinc?***

QUESTION NO. 136. ***Which is the best pot for sheet galvanizing, one built up from heavy boiler plate, or a cast pot? If a cast pot, about what analysis?***

QUESTION NO. 137. ***What is the mechanism of the iodine etch for the deep etching of steel?***

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

TESTING IRON TO CONTROL THE PROPERTIES OF CASTINGS. By G. W. Gilderman, Mishawaka, Ind.

The above article was presented at the annual meeting of the American Foundrymen's Association, Milwaukee, October 11th to 16th. The author describes tests of irons which he has made, first for the benefit of the customer, and secondly for the foundryman to check his own practice. He states that it is a difficult problem to provide a suitable test that will cover the varied lines of castings manufactured through the country. Factors that make test bars unreliable are discussed and examples given.

SULPHUR AS A HARDENING AGENT. By R. H. Palmer, in *Foundry*, November 15th, page 894.

A series of experiments have been carried on by the author of this article to determine the relative hardening value of varying amounts of sulphur added to iron which later was poured into chill molds.

INFLUENCE OF NICKEL AND CHROMIUM UPON THE SOLUBILITY OF STEEL (IN RELATION TO CORROSION). By Dr. W. H. Hatfield, Brown-Firth Research Laboratories, Sheffield.

The above was presented at the September, 1923, meeting of the Iron and Steel Institute. In this paper it is proposed to discuss a series of experiments designed to give information upon the effect of alloying separately, and together, the elements chromium and nickel with iron, the carbon content being varied; and to discuss the solubility of such alloys in nitric acid, sulphuric acid and hydrochloric acid.

ROLLING REFINES GRAIN STRUCTURE. By W. J. Crook, associate professor of metallurgy, Leland Stanford University, Stanford University, Calif., and consulting metallurgist engineer, Pacific Coast Steel Co., San Francisco, in *Iron Trade Review*, November 20th, page 1365.

The above article explains how hot rolling reduces the grain size of low carbon steel and states that further refinement is afforded by annealing. Experiments carried on contradict the theory that no change in size occurs below the transformation point.

HORIZONTAL RING INDUCTION FURNACES. By J. A. Seede, General Electric Co., Schenectady, N. Y., in *Iron Age*, November 13th, page 1281.

In this article the induction furnace is compared with the electric arc furnace, and the attractive features of induction melting are discussed. The results from a 6-ton induction furnace are given.

ANNEALS BRASS TUBES ELECTRICALLY. By R. M. Keeney, industrial heating engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, in *Iron Trade Review*, November 20th, page 1370.

This article is an abstract of a paper presented at the forty-sixth general meeting of the American Electrochemical Society, Detroit, October 2nd to 4th, and states that a manufacturer has replaced the wood-fired with the electric furnace to anneal small brass tubing. The advantages of low labor cost and the reduction in time needed for pickling are noted.

HEAT TREATMENT OF CARBON AND HIGH-SPEED STEEL TOOLS. By J. K. Wood, consulting engineer, New York City, in *American Machinist*, November 20th, page 791.

In this article are given the determining factors in the development of metal-cutting tools as well as the heat treatment for carbon-steel tools. Compositions and heat treatment for high-speed steel tools are also discussed.

MANUFACTURE OF TAPERED ROLLER BEARINGS. By M. T. Lathrop, vice-president, Timken Roller Bearing Co., Canton, Ohio, in *American Machinist*, November 20th, page 803.

This is the first series of an article which will cover the continuous process of the manufacture of tapered roller bearings from the ore pile to the finished product. In this chapter the uniform control of material, processes, assembly, installation and use are covered.

THE COLD-WORKING OF STEEL WITH REFERENCE TO THE TENSILE TEST. By John Stead.

This paper was presented at the May, 1923, meeting of the Iron and Steel Institute. The experiments described therein were originally undertaken with the object of finding some relation between the tensile strength of wire, and that of the steel from which it was drawn. No definite relation was obtained, but some of the results are of interest from the point of view of cold-working generally.

SOME PROPERTIES OF STEELS CONTAINING GLOBULAR CEMENTITE. By C. H. Desch and Aubrey T. Roberts.

The above paper was presented at the May, 1923, meeting of the Iron and Steel Institute. The authors state that the work described was undertaken to determine certain properties of high-carbon steels in which the cementite had been brought completely into the globular condition by combined thermal and mechanical treatment. The first section deals with the effect of heat treatment on a carbon steel, slowly cooled from the molten state, and heated under such conditions as to produce globular cementite. The second part of the paper describes experiments on the steels used in the manufacture of safety-razor blades, with an account of the factors which determine their efficiency.

News of the Chapters

STANDING OF THE CHAPTERS

IN the last issue of TRANSACTIONS was published the relative membership standing of the 29 chapters of the Society as of October 1. The following list gives the standing as of November 1. While there have been membership gains in Groups I and II, there has been no change in the relative position of the chapters, but in Group III, Schenectady and Rochester have gained one place, whereas South Bend and Springfield have lost one place.

I	II	III
1. Detroit (283)	1. Hartford (130)	1. Lehigh Valley (109)
2. Pittsburgh (275)	2. Golden Gate (100)	2. New Haven (55)
3. Chicago (266)	3. Syracuse (77)	3. Tri City (55)
4. Cleveland (240)	4. Milwaukee (74)	4. Worcester (47)
5. Philadelphia (221)	5. Cincinnati	5. Los Angeles
6. Boston (211)	6. Indianapolis	6. Washington
7. New York (199)	7. Buffalo	7. SCHENECTADY
	8. North West	8. South Bend
	9. St. Louis	9. Providence
		10. Rockford
		11. ROCHESTER
		12. Springfield
		13. Toronto

BOSTON CHAPTER

The Boston chapter of the American Society for Steel Treating held a meeting on October 30th in Room 5-330 of the Massachusetts Institute of Technology. The speaker of the evening was George A. Richardson of the Bethlehem Steel Company, who gave a general talk on the "Manufacture of Steel," accompanied by moving pictures. There were several reels which covered practically all phases of the industry from the mining of the ore to the melting and rolling of the finished product. This meeting was well attended.

The chapter held their November meeting on the 21st of the month at the Edison Electric Illuminating Company, Roxbury, Mass. Dr. B. Egeberg, metallurgical department, Halcomb Steel Co., Syracuse, N. Y., was the speaker of the evening, choosing for his subject, "Some Structural Alloy Steels." This talk was confined to the application, characteristics and heat treatment of alloy steels, including the recent development with alloys of nickel chromium and vanadium.

CHICAGO CHAPTER

The Chicago chapter of the American Society for Steel Treating held their regular monthly meeting on Thursday, November 13th, at the City Club. The subject, "Industrial Europe," was given by Hyman Bornstein, metallurgist, Deere and Co., Moline, Ill., and O. T. Muehlemeyer, metallurgical engineer, formerly with Barber Colman Co., Rockford, Ill. These two gentlemen were able to give first hand information about European conditions, and their presentations were very interesting.

CINCINNATI CHAPTER

The regular monthly meeting of the Cincinnati chapter of the American Society for Steel Treating was held on November 13th at 8:00 p. m. in the Ohio Mechanics Institute, at which time Dr. J. Culver Hartzell, chairman of the executive committee of the chapter and president of the Ohio Lesgas Corp., presented, "The Story of Fire Clay Refractories," illustrated by motion pictures. Dr. Hartzell gave a brief discussion of clays and their origin with special reference to refractories used in brass, bronze, iron and steel melting furnaces of electric and fuel types. The motion pictures showed the mining and preparation of clays and their manufacture into refractories.

CLEVELAND CHAPTER

The third regular monthly meeting of the Cleveland chapter was held in the ball-room of the Hotel Winton, Friday evening, Nov. 21st, 1924, at 8:00 p. m. Approximately 200 members and guests were present.

J. M. Watson, metallurgical engineer of The Hupp Motor Car Corporation gave an illustrated lecture on "The Heat-Treatment of Automobile Parts," exhibiting motion pictures which were taken at the new Jackson plant of this company by the U. S. Bureau of Mines. This excellent film shows some of the most recent developments in modern heat-treating, and it is well worth seeing. Several who were present had seen this picture previously, but came for a second view of it, and did not count their time wasted.

A. W. F. Green, well-known and active secretary of the Philadelphia chapter was also present at this meeting and gave an informal talk on plans of his chapter for the coming season.

Dinner was served at 6:45 p. m. preceding the meeting.

DETROIT CHAPTER

The November meeting of the Detroit chapter of the American Society for Steel Treating was held on Monday, the 17th, at 8:00 p. m. on the 15th floor of the General Motors Building. "Modern Developments in Heat Treating Equipment" was the subject of a motion picture presented by J. M. Watson, metallurgist, Hupp Motor Company, which illustrated the very complete heat treating plant recently constructed and equipped at the Jackson, Michigan, plant of the Hupp Motor Company. L. Thomas, metallurgist, Timken-Detroit Axle Company, described by means of a set of slides, a number of special installations of electric, oil and gas-fired furnaces and auxiliary equipment, many of which had been built in the Detroit district. Dinner was served at 6:30 p. m. preceding the meeting.

GOLDEN GATE CHAPTER

The November meeting of the Golden Gate chapter of the American Society for Steel Treating was held on Saturday, the 8th of the month, in the Engineers Club, San Francisco, at 6:30 p. m. The executive committee of the chapter has arranged a series of lectures on steel, which began with the November meeting. Each lecture will cover a definite phase of the subject so that the whole will tell the complete story from the ore to the finished product. After an introduction by F. B. Drake of the Johnson Gear Co., W. F. Dietrich, associate professor of metallurgy, Stanford University, presented the first lecture of the series entitled, "Iron Ores and the Blast Furnace." A moving picture entitled, "The Manufacture of Steel," was shown as a final feature of the evening.

HARTFORD CHAPTER

On November 11th at 7:45 p. m., the Hartford chapter of the American Society for Steel Treating held their meeting in the assembly hall of the Hartford Electric Light Co., Hartford. Z. L. Sault, president of the New England Annealing and Tool Co., Boston, presented an interesting paper entitled, "Commercial Heat Treating." Mr. Sault, who has had a wide experience in the commercial heat treatment of steel, gave a very capable presentation which brought forth much valuable discussion.

INDIANAPOLIS CHAPTER

An illustrated lecture entitled, "The Story of Alloy Steel," produced by the Interstate Iron and Steel Company, Chicago, in co-operation with the Bureau of Mines, was the feature of the November 10th meeting of the Indianapolis chapter of the Society. This picture was very interesting and highly educational. Dinner was served at 6:30 p. m. at the Y. M. C. A. auditorium previous to the meeting.

LEHIGH VALLEY CHAPTER

The Fall meeting of the Lehigh Valley chapter of the American Society for Steel Treating was held on November 14th in the Easton Public Library, Easton, Pa. Dr. William Campbell, D.Sc., Ph. D., talked on "Metallography Theory and Practice." Dr. Campbell is consulting metallurgist for the Brooklyn Navy Yard, and occupies the Howe Chair of Metallurgy at Columbia University. Dr. Campbell, however, reached his entire audience, comprised of professors, research engineers, steel makers, steel users, engineers, college students and heat treaters, by a presentation of the subject which illustrated the absolute non-necessity of talking "high-brow" in order to present a so-called "high-brow" subject. The language was that understood by everyone, and Dr. Campbell pointed out that a "high-brow" is a "high-brow" in name only, and that there is no necessity for confusing the "man at the fire" with a lot of long technical names which he could not and would not understand.

Dr. Campbell reviewed the history of metallography, explaining that

it did not require a microscope, and that it was the science of the constitution of metals and alloys, their structures and physical properties. The requirements for metallurgical reports and the necessity for making these reports intelligible to their readers were emphasized. A short, clear explanation of the phase rule was followed by illustrations of constitutional diagrams showing that this contained all the information which was presented by the phase rule and in language which was much easier to understand. The iron carbon diagram and its use in heat treatment was brought forth in a masterly way. The uses of ternary diagrams were explained by the copper-antimony-tin and the lead-antimony-tin diagrams which gave the compositions of most of the commercial babbitt metals. All of these diagrams were profusely illustrated with wonderful micrographs at high and low magnifications, and the co-relation between the diagram and the micrograph was explained.

The use of metallography as a means of examination of metals was described and illustrated by typical failures and micrographs, all of these being explained in a manner which was intelligible and understandable to the listner who did not have any knowledge of microstructure. Dr. Campbell showed structures which were obtained with heat treatments purposely calculated to ruin the metal. Although the general impression would be that these treatments were not applied in works, practice, Dr. Campbell showed that they were applied by giving actual examples of actual failures caused by each of these treatments.

A thought as to our future progress in steel making was given by showing the application of ternary diagrams to the explanation of the reaction constituents to be found in blast furnace slags. Progress along these same lines is to be greatly desired on Open Hearth and similar slags.

Dr. Campbell also showed that the craft of steel treating is the oldest and most honorable craft, antedating that of the gold smiths guilds. His illustrations of the processes in early use were accompanied with very entertaining short descriptions.

LOS ANGELES CHAPTER

The Los Angeles chapter of the American Society for Steel Treating were very much pleased to have as their guest, W. H. Eisenman, national secretary of the Society, at their November 12th meeting, held at the Los Angeles Creamery Cafeteria. Mr. Eisenman spoke on "Steel Treating—Its Past, Present and Future." He also spoke on the aims, purposes and accomplishments of the Society. Dinner was served at 6:30 p. m. preceding the meeting.

MILWAUKEE CHAPTER

M. E. Greenhow, National Brake and Electric Co., Milwaukee, was the speaker for the October 31st meeting of the Milwaukee chapter of the Society, which took place at Hotel Blatz, at 8:00 p. m. The title of Mr. Greenhow's presentation was "Acid Open Hearth Steel Castings," includ-

ing the general practice of open hearth and foundry. Dinner was served at 6:30 p. m. preceding the meeting .

NEW HAVEN CHAPTER

The New Haven chapter of the American Society for Steel Treating held a meeting on September 17th at the Mason Laboratory of Yale University. Dr. John A. Mathews, of the Crucible Steel Company of America, gave a very capable presentation entitled, "Non-Corrosive and Heat Resisting Steels."

The chapter held their October meeting on the 31st of the month at the Hammond Laboratory of Yale University at which time Radclyffe Furness, superintendent of the melting department of the Midvale Company, gave a practical talk on "Open Hearth Steel." An interesting and instructive discussion followed this presentation.

NEW YORK CHAPTER

At the November 19th meeting of the New York chapter of the Society, Edgar C. Bain, research metallurgist, Union Carbide and Carbon Research Laboratories, Long Island City, delivered a most interesting and informative address on the fundamentals of high speed steel.

On the evening of December 17th, the chapter will hold a rather unusual session on the subject of steels for railroads. The Program Committee, of which E. F. Cone is chairman, has arranged to have three or four speakers discuss various phases of the subject. Among these will be L. W. Fry, metallurgical engineer, Standard Steel Works, Burnham, Pa., who will discuss steel for locomotives. There will also be a representative of the New York Central and possibly another railroad man. The subject will be more or less summarizbed by L. E. Howard, the well known specialist of the Interstate Commerce Commission, Washington. There is no doubt that such a program merits a large attendance as the technical and practical phases will predominate, and there is an opportunity to absorb a large amount of valuable information.

NORTH WEST CHAPTER

At 8:00 p. m. on November 18th, the North West chapter of the Society held a meeting at the Manufacturers' Club. The speaker of the evening was A. H. d'Arcambal, metallurgist of the Pratt and Whitney Co., Hartford, who chose for his subject: "Carbon Tool and High Speed Steel Used in the Manufacture of Small Tools." Dinner was served at the Elks' Club at 6:30 p. m. preceding the meeting.

PITTSBURGH CHAPTER

The November meeting of the Pittsburgh chapter of the American

Society for Steel Treating was held in the Rose Room of the Fort Pitt Hotel on Thursday, the 8th. The speaker of the evening was Wm. J. Priestley of the Electro Metallurgical Sales Company, whose subject was "The Relation between the Rate of Cooling and the Structure of the Steel Ingot." The resulting structure from casting into both sand and iron molds of various wall thicknesses was illustrated by macrographs. The effect of the different rates of cooling upon the size and location of segregations was also very clearly brought out both by slides showing the size and areas of the segregations and by tensile figures. Mr. Priestley pointed out the reasons for some of the cracks which occur in ingots and described the advantages and disadvantages of different shaped molds and of bottom or top pouring. The interest in Mr. Priestley's subject was shown by the large attendance at this meeting and the subsequent lengthy discussion of its many related phases. The possibility of relocating impurities in steel by heat treatment was discussed at considerable length.

Our attention has been directed to an error which occurred in the report of the last meeting of the Pittsburgh chapter. It was stated that the steering knuckles made by the Hupp Motor Car Corporation were carburized and subsequently heat treated. This company does not carburize their steering knuckles. They are, however, heat treated.

ROCHESTER CHAPTER

On November 10th, the Rochester chapter of the Society held a meeting at Mechanics Institute at 8:00 p. m. "Malleable Iron, Its History and Development," was the title of a paper presented by E. A. Touceda. This was a very capable address inasmuch as Mr. Touceda has had broad, practical experience in the metallurgy of iron and steel, and is one of the foremost men in this country on malleable iron today. An informal dinner was served at 6:15 P. M.

ST. LOUIS CHAPTER

The regular monthly meeting of the chapter was held on September 15th at the American Annex Hotel. The speaker of the evening, J. B. Schuck, chief engineer, St. Louis Screw Company, choose for his subject, "X-ray and its Value to Metallurgy." Mr. Schuck is experimenting along these lines, and has been doing some very successful work. An interesting discussion ensued following this presentation.

SCHENECTADY CHAPTER

The regular meeting of the Schenectady chapter of the American Society for Steel Treating was held in the Rose Room of the Twentieth Century Restaurant on Thursday evening, October 30th. Dinner was served at 6:30 p. m., after which a very interesting talk was given by W. E. Ruder, metallurgist of the General Electric Co., on "The Production of Magnetic and Electrical Sheets."

SOUTH BEND CHAPTER

On Tuesday, November 25th, the South Bend chapter of the American

Society for Steel Treating held a meeting at 7:45 p. m. at the Studebaker Corporation. "High Speed Steel and its Treatment for Cutting Tools" was the subject of a paper by E. C. Baum, Metallurgist, Illinois Tool Works. L. F. Maurer, manager of the methods and standards department of the South Bend plants of the Studebaker Corporation, also gave an address entitled, "Layout of a Forge Shop and a Heat Treating Department." These presentations aroused much valuable discussion.

SPRINGFIELD CHAPTER

The regular monthly meeting of the Springfield chapter was held on November 25th at 8:00 p. m. in the physical laboratory of the U. S. Armory, at which time a demonstration of machines and actual tests was given by local members. A get-together dinner was held at the Highland Hotel at 6:30 p. m. preceding the meeting.

SYRACUSE CHAPTER

C. L. Ipsen of the General Electric Company addressed the November 17th meeting of the Syracuse chapter of the American Society for Steel Treating, which was held at the Onondaga Hotel at 8:00 P. M., on the "Principles of Construction and Application of Electric Furnaces for Heat Treating and Kindred Uses." Dinner was served at 6:30 p. m. at the University Club.

TRI CITY CHAPTER

On Thursday, October 23rd, the Tri City chapter of the Society held a meeting at the Davenport Chamber of Commerce at 7:45 p. m. E. G. Prentice of the American Steel and Wire Co., Waukegan, Ill., gave an interesting paper entitled, "Spring Manufacture." Dinner was served at 6:45 p. m. preceding the meeting.

The November meeting of the chapter was held on the 20th of the month at the Davenport Chamber of Commerce. A. H. d'Arcambal, chief metallurgist, Pratt and Whitney, Hartford, gave an address entitled, "Carbon and High Speed Tool Steels." This presentation was illustrated with specimens of tool steel.

WORCESTER CHAPTER

G. B. Wilkes, associate professor of physics, Massachusetts Institute of Technology, addressed the November 13th meeting of the Worcester chapter of the American Society for Steel Treating, which was held at the Worcester Electric Light Company. The subject of Prof. Wilkes' paper was "Insulating Materials," which covered low, intermediate and high temperature insulating materials; what they are; where they come from, and why they insulate." Dinner was served at 6:30 p. m. preceding the meeting.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

ABDUN-NUR, E. A., (Jr-8), student, Massachusetts Institute of Technology, Cambridge, Mass.

AICHER, J. F., (A-S), industrial gas engineer, Pacific Gas and Electric Co., 241 Stevenson St., San Francisco.

ALBOUZE, A. R., (A-7), industrial gas engineer, sales department, Pacific Gas and Electric Co., San Francisco.

ALEXANDER, S. C., (M-10), assistant purchasing agent, California and Hawaiian Sugar Refining Corp.; *mail* 512 Van Ness Ave., San Francisco.

ALLAN, J. H., (M-9), assistant to works manager, International Harvester Co., Chicago.

ANDERSON, O. E., (M-9), foreman, R. Emsco Steel Products Co.; *mail* 1721 East Florence Ave., Los Angeles.

ANDREWS, C. W., (M-10), metallurgist, research department, American Rolling Mill Co.; *mail* Y. M. C. A., Middletown, Ohio.

ARVINE, A. R., (M-11), University of Illinois; *mail* 305 West High St., Urbana, Ill.

ATKINS, E. C., (M-8), E. C. Atkins and Co., Indianapolis.

ATKINS, H. C., (M-8), E. C. Atkins and Co., Indianapolis.

ATKINS, W. A., (M-9), E. C. Atkins and Co., Indianapolis.

BAGSHAW, W. J., (M-1), W. H. Bagshaw Co., Lowell, Mass.

BAKER, W. J., (M-10), metallurgist, Strom Ball Bearing Mfg. Co.; *mail* 3339 Polk St., Chicago.

BARRETT, G. N., JR., (M-10), assistant metallurgist, Park Drop Forge Co.; *mail* 1886 East 97th St., Cleveland.

BARRY, J. F., (M-10), vice-president and general manager, Rival Safety Razor Corp.; *mail* 4823 Crutcher St., Dallas, Texas.

BATCHELDER, G. M. P., (M-11), chief inspector, Rolls Royce of America, Inc.; *mail* 31 Clarendon St., Springfield, Mass.

BATES, A. A., (Jr-11), student, Case School of Applied Science; *mail* 2107 Adelbert Road, Cleveland.

BENEKER, J. C., (M-9), metallurgist, Pacific Coast Steel Co., Seattle, Wash.

BENNETT, C. G., (M-5), American Locomotive Co.; *mail* Box 611, Schenectady, N. Y.

BERGERSON, M. W., (M-9), foreman, heat treating department, Ingersoll-Rand Co., Phillipsburg, N. J.; *mail* 918 Wilkesbarre St., Easton, Pa.

BIDDLE, H. C., (M-5), instructor, State Teachers College; *mail* 2815 Stuart Ave., Berkley, Calif.

BIERWIRTH, E. A., (M-10), tool room foreman, Kelsey Wheel Co.; *mail* 3768 Humboldt Ave., Detroit.

BIESER, C. W., (S-10), superintendent, Gruen National Watch Case Co., Cincinnati, Ohio.

BILL, LOUIS, (M-11), foreman, blacksmith shop, J. A. Fay and Egan Co., Oakley, Cincinnati, Ohio.

BLACKBURN, H. A., (A-9), salesman, Norton Co., Cleveland; *mail* 1450 Rockway Ave., Lakewood, Ohio.

BLADEL, A. A., (Jr-10), draftsman, Bettendorf Co., Bettendorf, Iowa; *mail* 540 22nd Ave., Rock Island, Ill.

BLANEY, C. M., (A-9), salesman, Lancaster Steel Products Co., Boston.

BOWERSOX, E. L., (Jr-10), student, Case School of Applied Science; *mail* 1456 East 116th St., Cleveland.

BRADLEY, D. T., (M-7), assistant metallurgist, American Auto Parts Co., Detroit.

BREED, C. H., (A-10), district sales agent, Poldi Steel Corporation of America; *mail* Room 908-983 Main St., Hartford.

BRIGGS, H. B., (M-7), Wheelock, Lovejoy and Co., Inc., Cambridge, Mass.

BROADWELL, R. M., (M-10), plant engineer, Lake Erie Bolt and Nut Co., Cleveland.

BRODHEAD, RICHARD, (M-9), inspector, metallurgical department, Ingersoll-Rand Co., Phillipsburg, N. J.; *mail* 810 Paxinosa Ave., Easton, Pa.

BUBB, H. D., JR., (Jr-10), student, Case School of Applied Science; *mail* 2111 Abington Road, Cleveland.

BURNETT, G. F., (M-10), production manager, R. N. Brodie Co., Oakland, California.

BURNHAM, R. C., (Jr-10), student, Case School of Applied Science; *mail* 1527 Cohasset Ave., Lakewood, Ohio.

CAMERON, A. E., (M-10), associate professor, department of mining, University of Alberta, Edmonton, Alberta, Canada.

CAMERON, G. H., (A-9), Standard Gauge Steel Co., 141 Milk St., Boston.

CAMPBELL, WM., (M-7), Columbia University, New York City.

CARPENTER, C. H., (M-9), R. D. No. 3, Westmoreland County, Irwin, Pa.

CARR, W. E., (M-10), blacksmith, W. E. Carr Co.; *mail* 191 Robbins St., Waltham, Mass.

CARROLL, WALTER, (M-11), vice-president, Carroll Chain Co.; *mail* 265 Hosack St. Columbus, Ohio.

CARVELLI, GUSTAF, (M-9), chief draftsman, Curtiss Aeroplane and Motor Co.; *mail* 413 Massachusetts Ave., Buffalo, N. Y.

CASE SCHOOL OF APPLIED SCIENCE, (S-10), department of metallurgical and mining engineering, Cleveland.

CHADDERTON, J. E., (A-8), salesman, John Illingworth Steel Co.; *mail* Box 2031, Boston.

CHAMBERLAIN, V. U., (M-11), superintendent, drop forge department, Bethlehem Steel Co., Bethlehem, Pa.

CHAMBERS, G. W., (M-10) production department, Reliance Steel Casting Co., Pittsburgh.

CHAMPION, ALBERT, (M-8), president, A. C. Spark Plug Co., Flint, Mich.

CHRISTIE, R. E., (M-10), Crucible Steel Company of America, New York City.

CLARK, E. E., (M-10), general manager, Masterench Corp., Turlock, Calif.

CLARK, F. E., (M-8), sales engineer, Republic Carbon Co., Milwaukee.

CLARKE, J. T., (S-7), A. Leschen and Sons Rope Co., St. Louis.

COLLINS, E. C., (S-10), president, Crucible Steel Company of America, New York City.

COOPER, E. J., (M-11), heat treating department, Eaton Axle and Spring Co.; *mail* 1193 East 145th St., Cleveland.

COBK, H. V., (M-10), foreman, die department, Youngstown Sheet and Tube Co., Indiana Harbor, Ind.; *mail* 6806 Ridgeland Ave., Chicago.

CORSON, C. E., (M-11), metallurgist in charge of production, Edgewater Steel Co.; *mail* 313 Third St., Oakmont, Pa.

COX, H. M., (M-10), sheet and strip metallurgist, Central Steel Co., Massillon, Ohio.

CRITCHLOW, G. N., (A-10), district sales manager, Pittsburgh Crucible Steel Co., General Motors Bldg., Detroit.

CULVERWELL, J. M., (A-5), manager, Kortick Manufacturing Co.; *mail* 335 First St., San Francisco.

CUMMINGS, E. E., (M-9), foreman, heat treating, Delco Light Co., Dayton, Ohio.

DELAWARE VALLEY FORGE CO., INC., (S-11), 2300 East Tioga St., Philadelphia.

DERHAMMER, C. W., (M-10), president, Lakeside Steel Improvement Co., 5418 Lakeside Ave., Cleveland.

DESCH, C. H., (M-9), professor of metallurgy, The University, Sheffield, England.

DE VAN, F. J., (A-11), salesman, Wheelock, Lovejoy and Co., Inc., Chicago.

DE VINE, H. A., (Jr-11), student, Lewis Institute; *mail* 300 West 74th St., Chicago.

DIGGES, T. G., (M-10), associate physicist, Bureau of Standards, Washington, D. C.; *mail* 25 Taylor Ave., Clarendon, Va.

DOSWELL, H. R., (M-9), technical foreman, U. S. Aluminum Co., Fairfield, Conn.

DOUGLAS, E. J., (M-6), machine shop superintendent, Dalny Oil Syndicate, Inc., Long Beach, Calif.

DOWNS, E. A., (M-8), inspector, North East Electric Co.; *mail* 852 Monroe Ave., Rochester, N. Y.

DREVITSON, C. B., (M-10), chief engineer, International Development Co., Malden, Mass.

EAGAN, T. E., (Jr-8), student, Missouri School of Mines, Rolla, Mo.

EWALD, JOSEPH, (M-11), foreman, American Swiss File and Tool Co.; *mail* 1028 Anna St., Elizabeth, N. J.

FARREN, P. C., (M-10), chemist and inspector, Bourne-Fuller Co., Upson Works; *mail* 12701 Arlington Ave., Cleveland.

FILSON, C. C., (Jr-10), assistant in laboratory, Lamson and Sessions Co., Kent, Ohio.

FISCHER, E. F., (Jr-8), research assistant, Aluminum Company of America; *mail* 3385 West 90th St., Cleveland.

FISHER, V. B., (M-11), sales metallurgist, Carpenter Steel Co., Philadelphia.

FITZGIBBONS, T. J., (M-10), sales department, Bethlehem Steel Co., Bethlehem, Pa.

FLIEDNER, C. S., (M-10), associate engineer, Aero Engine Laboratory, Philadelphia Navy Yard; *mail* 1807 Spruce St., Philadelphia.

FLOWERS, A. E., (M-10), engineer in charge of development, De Laval Separator Co., Poughkeepsie, N. Y.

FREDERICK, W. L., (A-10), partner, Frederick, Traugott and Allen Co., Philadelphia.

FREYBERGER, W. F., (M-11), assistant metallurgist, A. Schrader's Sons, Inc., Brooklyn, N. Y.

FRISCHMAN, T. A., Jr., (Jr-10), student, Case School of Applied Science; *mail* 1641 East 117th St., Cleveland.

FRONEK, S. A., (Jr-10), student, Case School of Applied Science; *mail* 6063 Hillman Ave., Cleveland.

FRONERT, E. T., (M-10), chemical assistant, Watertown Arsenal, Watertown, Mass.; *mail* 91 Porter St., Somerville, Mass.

GARLAND, G. C., (A-10), sales engineer, General Furnace Co., Boston.

GAWTHROP, F. G., (M-11), chief inspector, Holt Manufacturing Co.; *mail* 1855 McKinley Ave., Stockton, Calif.

GAYLORD, H. B., (S-11), district manager, Carpenter Steel Co., Philadelphia.

GEARHART, J. R., (A-10), manager, James H. Knapp, San Francisco.

GERBEAUX, ANDRE, (M-10), engineer, manufacturing department, International General Electric Co., Schenectady, N. Y.

GETTY, H. A., (A-10), district manager of sales, Wyckoff Drawn Steel Co., Little Bldg., Boston.

GLASS, J. C., (A-7), salesman, Midvale Co., Cleveland.

GOODPASTURE, J. M., (M-10), superintendent, melting department, Henry Disston and Sons, Philadelphia.

GORDON, F. F., (M-9), technical director, Spear & Jackson, Ltd., Sheffield.

GORDON, W. R., (M-10), Box 584, Charlotte Station, Rochester, N. Y.

GOUGEON, E. N., (Jr-10), student, Massachusetts Institute of Technology; *mail* Box 202, M. I. T., Cambridge, Mass.

GRAU, W. S., (M-11), production superintendent, Union Tool Co., Torrance, Calif.; *mail* 1358 West 51st St., Los Angeles.

GRIFFIN, J. B., (A-8), vice-president in charge of sales, Griffin Manufacturing Co., Erie, Pa.

GROSVENOR, A. W., (Jr-11), student, Ohio State University; *mail* 176 15th Ave., Columbus, Ohio.

GUNNING, J. M., (M-10), foreman, American Car and Foundry Co., Berwick, Pennsylvania.

GYGI, P. J., (M-10), metallurgist, Champion Machine and Forging Co.; *mail* 8105 Dorver Ave., S. E., Cleveland.

HABART, HERBERT, (Jr-10), student, Case School of Applied Science; *mail* 4115 East 138th St., Cleveland.

HAGBERG, E. E., (M-9), efficiency engineer, International Harvester Co., Chicago; *mail* 132 Blackstone Ave., La Grange, Ill.

HAGENBUSH, J. E., (M-9), foreman, Star Drilling Machine Co., Akron, Ohio.

HAMER, CLARENCE, (M-10), head of tool division, Remington Cash Register Co.; *mail* 259 Second St., Ilion, N. Y.

HAMMOND, C. J., (Jr-10), student, Case School of Applied Science; *mail* 2120 Cornell Road, Cleveland.

HANNON, C. H., (M-11), metallurgical department, General Electric Co., Pittsfield, Mass.

HARDY, T. W., (M-8), metallurgist, Timken Roller Bearing Co., Canton, Ohio.

HARLEMAN, S. T., (A-10), salesman, Henry Disston and Sons Co., Philadelphia.

HARRINGTON, R. F., (M-10), metallurgist, Hunt Spiller Mfg. Corp.; *mail* 383 Dorchester Ave., South Boston, Mass.

HARTFORD, H. K., (M-10), superintendent, Bourne-Fuller Co., Union Plant; *mail* 14300 South Park Blvd., Cleveland.

HARTSCHORN, D. S., (M-10), mechanical engineer, Darling Valve and Mfg. Co., Williamsport, Pa.

HEDGCOCK, W. C., (M-11), assistant chief mechanical engineer, American Steel Foundries, Chicago.

HESS, G. T., (M-10), superintendent heat treating and cold drawn department, Central Steel Co., Massillon, Ohio.

HOBSON, W. A., (M-9), inspector, Ingersoll-Rand Co., Phillipsburg, N. J.; *mail* 207 Northampton St., Easton, Pa.

HOEHLE, C. F., (M-11), assistant foreman, International Motor Car Co., Allentown, Pa.

HRUSKA, J. H., (M-9), chemist, International Harvester Co., Chicago; *mail* 6743 Riverside Drive, Berwyn, Ill.

HSIEH, SURGEON, (Jr-10), student, Case School of Applied Science; *mail* 8905 Hough Ave., Cleveland.

HUGHES, T. P., (M-11), instructor, forge practice, University of Minnesota, Minneapolis, Minn.

IGLEHEART, G. P., (M-11), production manager, 4 One Box Machine Makers, Rockaway, N. J.

JAMISON, E. E., (A-5), president, Jamison Steel Co., San Francisco.

JENKIN, ANTHONY, (M-10), professor of mining engineering, Case School of Applied Science, Cleveland.

JONES, J. E., (M-5), toolmaker, Columbia Steel Corp., Pittsburg, Calif.

JONES, R. H., (M-9), general manager, Herff-Jones Co., Indianapolis, Ind.

JUDGE, FRANKLIN, (M-8), general superintendent, Greenfield Tap and Die Co.; *mail* 78 Ridell St., Greenfield, Mass.

KEMMERLINE, J. F., (M-10), treasurer, Cornwell Quality Tool Co., Cuyahoga Falls, Ohio.

KEMPER, W. H., (M-10), metallurgist, Carpenter Steel Co., Reading, Pa.

KENNERSON, J. E., (M-10), mechanical superintendent, Trimont Mfg. Co., Boston.

KENYON, R. L., (M-10), assistant to metallurgist, American Rolling Mill Co.; *mail* 2806 Elmo Place, Middletown, Ohio.

KIENKER, H. F., (M-8), superintendent, Cisco Machine Tool Co.; *mail* 1417 Marlowe Ave., College Hill, Cincinnati, Ohio.

KLEES, A. L., (A-7), Combustion Utilities Corp., New York City.

KNIPPER, J. G., (M-10), supervisor, J. G. Knipper; *mail* 280 Orange St., Rochester, N. Y.

KUBES, F. W., (Jr-10), Cleveland Twist Drill Co., Cleveland.

LACROIX, T. M., (M-9), tool maker, Conner Mfg. Co., San Francisco; 2436 Russell St., Berkley, Calif.

LAMMERMAN, H. E., (M-10), assistant general manager, Simmons Manufacturing Co., Cleveland.

LARSON, VICTOR, (M-9), foreman, heat treating, Burgess-Norton Mfg. Co., Geneva, Ill.

LEONARD, P. A., (M-10), general foreman, forge shop and superheater, American Locomotive Co., Schenectady, N. Y.

LERCH, S. B., (M-11), tool hardener, Studebaker Corp.; *mail* 1013 East Calvert St., South Bend, Ind.

LEWIS, M. H., (M-10), assistant metallurgist, North East Electric Co.; *mail* 309 Parsells Ave., Rochester, N. Y.

LUND, JAMES, (M-9), foreman, Leland-Gifford Co.; *mail* 1025 Southbridge St., Worcester, Mass.

LUNDELL, OTTO, (A-10), vice-president and manager, Michigan Tool Co.; *mail* 147 Jos. Campau, Detroit.

LYONS, GUY, (M-10), foreman, heat treating department, Duckworth Chain and Mfg. Co.; *mail* 151 Maynard St., Springfield, Mass.

MACDONALD, F. A., (M-10), superintendent, Kortick Mfg. Co.; *mail* 345 First St., San Francisco.

MACQUARRIE, G. J., (A-9), salesman, Crucible Steel Company of America, Boston.

MALHOTRA, DES RAJ, (M-10), Aminpur St., Lyallpur, Punjab, India.

MATHEWSON, E. E., (M-7), chief engineer, Victory Manufacturing Co., Niles, Calif.

MATTHEWS, J. G., (M-9), proprietor, J. G. Matthews Co., Berea, Ohio.

MCCARTHY, D. J., (M-10), in charge of heat treating, U. S. Government Navy; *mail* 81 Cross St., Malden, Mass.

MCCLELLAND, W. M., (Jr-10), student, Case School of Applied Science; *mail* 2135 Adelbert Road, Cleveland.

MCGOHAN, G. W., (M-10), metallurgical assistant, American Rolling Mill Co.; *mail* 1912 Arlington Ave., Middletown, Ohio.

MCKEOWN, C. S., (M-10), machine shop superintendent, Fageol Motors Corp., Oakland, Calif.; *mail* 1204 Santa Clara Ave., Alemeda, Calif.

MEAD, D. W., (M-11), chemist, Diamond Chain Co.; *mail* 3335 School St., Indianapolis, Ind.

MERKT, T. B. J., (A-10), industrial sales supervisor, Brooklyn Union Gas Co.; *mail* 376 East 8th St., Brooklyn, N. Y.

MERRILL, C. F., (M-9), mechanical engineer, Draper Corp.; *mail* 9 Lake St., Hopedale, Mass.

MERRILL, J. L., (Jr-7), student, *mail* 2310 Prospect St., Berkeley, Calif.

MICHENER, R., (A-11), general sales agent, Crucible Steel Company of America, New York City.

MILLER, G. S., (M-9), superintendent, Wm. A. Rogers, Ltd., Northampton, Massachusetts.

MILTENBERGER, H., (M-10), metallurgist, Henry Disston & Sons, Philadelphia; *mail* Montgomery County, Philmont, Pa.

MORRIS, M. J. R., (M-9), research metallurgist, Central Steel Co.; *mail* 2011 Rodman St., Massillon, Ohio.

MORROW, R. T., (M-10), superintendent, Lakeside Steel Improvement Co., Cleveland.

MURRAY, L. G., (A-10), Vanadium Alloys Co., Boston.

MYERS, J. D., (M-10), secretary-treasurer, G. H. Porter Steel Treating Co., Cleveland.

NEWHAM, R. B., (M-11), hardener, E. W. Bliss and Co.; *mail* 7712 7th Ave., Brooklyn, N. Y.

NICKEL, D. F., (M-9), Box 14, Holt, Mich.

NISBET, A. W., (M-9), engineer in charge of power division, General Electric Co.; *mail* 29 Robinson St., Schenectady, N. Y.

OBERHUBER, W. F., (M-9), superintendent of maintenance, Philadelphia Electric Co.; *mail* 326 Windermere Ave., Lansdowne, Pa.

O'BRIEN, T. F., (M-11), foreman, National Lock Washer Co.; *mail* 40 Herman St., Newark, N. Y.

OLIVER, A. L., (A-10), assistant manager, California Cap Co.; *mail* 1540 San Pablo Ave., Oakland, Calif.

OSTROM, H. W., (M-10), chief chemist, Chicago, Milwaukee and St. Paul R. R.; *mail* 1045 39th St., Milwaukee, Wis.

PARLOUR, G. S., (M-10), engineer of insulation, Canadian General Electric Co., Peterboro, Ontario, Canada.

PATTULLO, M. D., (M-9), engineer, Reinforced Paper Bottle Co.; *mail* 1238 Eddy St., Chicago.

PEASE, R. M., (M-6), 3844 Walsh St., St. Louis, Mo.

PETERSON, W. C., (M-10), Room 4-137 General Motors Bldg., Detroit.

PHELPS, G. H., (M-8), chief metallurgist, Metropolitan Engineering Co.; *mail* 1250 Atlantic Ave., Brooklyn, N. Y.

POLLARD, G. E., (M-9), foreman sheet pickling, Columbia Steel Corp., Pittsburg, Calif.

PORTER, G. H., (M-10), president, G. H. Porter Steel Treating Co., Cleveland.

PORTER, T. A. Jr., (Jr-10), metallurgist department, Wetherell Bros. Co., Cambridge, Mass.; *mail* 9 Bellflower St., Dorchester, Mass.

PRICE, G. L., (A-10), New England manager, Hoskins Mfg. Co., Boston.

RAGATZ, R. A., (M-11), instructor of chemical engineering and metallography, University of Wisconsin, Madison, Wis.

REEDER, A. M., (M-10), metallurgist, Illinois Steel Co.; *mail* 612 Tyler St., Gary, Ind.

REILLY, A. G., (A-9), salesman, Babcock and Wilcox Tube Co.; *mail* 1207 Marquette Bldg., Chicago.

REINHARDT, G. A., (S-9), metallurgist, Western Clock Co., La Salle, Ill.

RHEAD, C. C., (M-10), metallurgist, Ternstedt Manufacturing Co.; *mail* 606 Harmon Ave., Detroit.

RICE, ROLAND, (Jr-5), student *mail* P. O. Box 91, Oakland, Calif.

ROWLAND, E. A., (Jr-11), University of Toronto, 151 Indian Road, Toronto.

ROWSING, HENNING, (M-11), furnace practice, Illinois Steel Co.; *mail* 204 Parks Ave., Joliet, Ill.

RUSSELL, E. E., (M-9), 966 East 55th St., Los Angeles, Calif.

SANDERSON, R. H., (S-10), member of firm, E. P. Sanderson Co., Cambridge, Mass.

SANS, JUSTIN, (M-11), Gogle Hand Forged Tool Co., San Carlo, Calif.

SATTERTHWAITE, GEORGE, (M-10), vice-president, Henry Disston and Sons, Inc., Philadelphia.

SCHAEFER, E. F., (M-11), director, bureau of city tests, University of Akron, Akron, Ohio.

SCHANNELL, G. E., (M-10), machinist, American Engineering Co.; *mail* 3123 Tulip St., Philadelphia.

SCHNURR, J. A., (M-10), foreman, North East Electric Co.; *mail* 24 Oakland St., Rochester, N. Y.

SCHURICHT, A. G., (S-9), chief chemist, Western Cartridge Co., East Alton, Ill.

SEAVEY, J. R., (M-11), Picatinny Arsenal, Dover, N. J.

SEETON, G. W., (A-9), district sales manager, Superior Steel Corp.; *mail* 750 Main St., Hartford.

SKIRVIN, J. B., (Jr-10), student, Case School of Applied Science; *mail* 2114 Stearns Road, Cleveland.

SLEATH, F. J., (A-8), salesman, Midvale Co., Cleveland.

SMALLEY, W. J., (M-6), heat treater, Lacy Manufacturing Co.; *mail* 3730 South San Pedro, Los Angeles, Calif.

SMITH, R. F., (A-7), sales manager, E. F. Houghton and Co.; *mail* 137 Lafayette St., New York City.

SMITH, R. H., (M-10), vice-president, Lamson and Sessions Co., Kent, Ohio.

SNADER, E. A., (M-10), metallurgical laboratory, U. S. Experimental Station; *mail* Maryland Hotel, Annapolis, Md.

SOLBERG, J. C., (M-11), engineer of tests, Watertown Arsenal, Watertown, Mass.

STEIN, F. F., (M-10), Wm. P. Stein and Co., Rochester, N. Y.

STEIN, W. P., (M-10), president, Wm. P. Stein and Co., Rochester, N. Y.

STICH, G. E., (M-9), vice-president, Aero Supply Manufacturing Co., New York City.

ST. JOHN, ANCEL, (M-8), consulting physicist, *mail* Room 404, 505 Fifth Ave., New York City.

STRONG, E. T., (S-9), master mechanic, Western Cartridge Co., East Alton, Ill.

STRUGGLES, F. L., (Jr-10), student, Case School of Applied Science; *mail* 3015 Yorkshire Road, Cleveland Heights, Ohio.

STUCKENHOLT, CASPER, (Jr-10), student, Case School of Applied Science; *mail* 1477 East 106th St., Cleveland.

SUMMERLEE, J. A., (M-8), general superintendent, Burroughs Adding Machine Co., Detroit.

TAYLOR, M. B., (M-11), research department, Trumbull Steel Co., Warren, Ohio.

TELFER, THOMAS, (A-8), industrial gas engineer, Industrial Gas Laboratory, San Francisco.

TERBUSH, F., (M-10), foreman, North East Electric Co.; *mail* 675 Post Ave., Rochester, N. Y.

THEWES, W. O., (A-9), treasurer and general superintendent, Ridge Tool Co., North Ridgeville, Ohio.

THOMPSON, R. S., (M-8), metallurgist, Washburn Wire Co., New York City.

TIERNEY, G. E., (M-10), foreman, North East Electric Co.; *mail* 85 Chandler St., Rochester, N. Y.

TOWNSEND, J. H., (S-9), superintendent, Hoopes and Townsend Co., Philadelphia.

TREVERROW, FREDERIC, (M-5), superintendent heat treating, Johnson Gear Co., Berkeley, Calif.

VAN DER VORN, JACOB, (M-10), general works manager, Wm. H. Keller, Inc., Grand Haven, Mich.

VON BEHREN, W. P., (Jr-10), student, Case School of Applied Science; *mail* 2111 Abington Road, Cleveland.

WAINWRIGHT, H. A., (M-5), vice-president and general manager, McQuay Norris Manufacturing Co., Connersville, Ind.

WEIDNER, C. A., (M-10), supervisor, C. A. Weidner Co.; *mail* 25 Carl St., Rochester, N. Y.

WEIDNER, C. E., (M-10), supervisor, C. A. Weidner Co.; *mail* 26 Raeburn St., Rochester, N. Y.

WELDON, H. S., (M-9), district manager, Canadian Inspection and Testing Co., Ltd., 406 Shaughnessy Bldg., Montreal, Quebec.

WHITNEY, L. C., (M-10), laboratorian, American Steel and Wire Co.; *mail* 766 Main St., Worcester, Mass.

WHITWORTH, E. A., (M-9), general superintendent, Bourne-Fuller Co., Cleveland.

WHITWORTH, T. E., (Jr-10), student, Case School of Applied Science; *mail* 10938 Drexel Ave., Cleveland.

WILKINS, CHARLES, (M-8), heat treater, Doehler Die Casting Co., 101-35 80th St., Woodhaven, N. Y.

WILLARD, M. V., (Jr-11), 473 West Marion St., Toronto, Canada.

WILLIAMS, C. H., (M-10), manager, steel works, Henry Disston and Sons, Philadelphia.

WINTON, G. M., (M-5), salesman, Jamison Steel Co., San Francisco; *mail* 6441 Harmon Court, Oakland, Calif.

WOLF, F. L., (M-11), technical superintendent, Ohio Brass Co., Mansfield, O.

WORTH, C. S., (M-11), chief engineeer, Worth Production Co.; *mail* 1032 Harper Ave., Los Angeles, Calif.

YAP, CHU PHAY, (Jr-10), P. O. Box 275, Golden, Colorado.

ZIEN, Z. P., (Jr-9), student, Massachusetts Institute of Technology; *mail* 96 Trowbridge St., Cambridge, Mass.

ZIV, G. F., (M-10), president, Ziv Steel Co., 4423 West Kinzie St., Chicago.

Items of Interest

THE Central Steel Company of Massillon, Ohio, manufacturers of Agathon alloy steels, announce the appointment of A. B. Cooper as their Philadelphia district sales manager with offices in the Widener Building. Mr. Cooper has been connected with the steel industry for 17 years in both operating and sales work, and is well known in the Philadelphia territory, where he was formerly identified with the Tacony Steel Company and the Penn Seaboard Steel Corporation.

The American Forge Company of Chicago recently published a booklet entitled, "AmForge Upset Forgings," in which they state "that the superiority of upset forgings for gear work was so evident and so pronounced that a majority of engineers lost no time in insisting upon this process for their transmission forgings." The resulting demand for these products was so great that the company built a plant, which they say is the largest and only exclusive upset forging plant in the world, with a capacity of producing 1500 tons of forgings per month.

E. Leitz and Company, New York City, have announced that they have discontinued their well-known metallurgical equipment, and in its place have recently introduced the new Leitz Micrometallograph, Model 1924. This new equipment, while embodying all the advantages of their former model, presents many novel outstanding features, which include a rigid locking device to prevent the weight of a heavy specimen disturbing the focus; a fine adjustment, acting directly on the objective, independent of the coarse adjustment; improved vertical illuminator; oblique and conical stop illumination; a powerful illuminating collimator lens system and an independent camera observation arrangement. Their recent publication, catalog No. 1057, containing photographs displaying the relief and increase of visibility of structural details due to conical stop illumination, may be obtained by addressing E. Leitz and Company, Inc., 60 East 10th Street, New York City.

An appointment of interest to metallurgists is that of F. C. A. H. Lantsberry as managing director of William Jessop & Sons Limited, the well known steel manufacturers of Sheffield, England. Mr. Lantsberry, though his professional activities have been mainly in regard to steel, has shown a great interest in metal research. He received his early training with the British Westinghouse Company, at Trafford Park, Manchester. For nine years he was chief of the works and research laboratory of the Birmingham Small Arms Company's Laboratory. Later Mr. Lantsberry was transferred to Sheffield where he served for some years, first as works manager

and afterwards as general manager. During his stay in Birmingham he was a frequent contributor at the meetings of the Local Section of the Institute of Metals and the Birmingham Metallurgical Society, and each of these bodies in turn elected him to its presidential chair. For three years he was engaged in metallurgical work at the National Physical Laboratory, Teddington. He is the joint author with Dr. Rosenhain of the Ninth Report to the Alloys Research Committee of the Institution of Mechanical Engineer. At the Boston Convention of the Society he presented a paper which will be published in a later issue of TRANSACTIONS.

It is reported that Cornell University and the University of Michigan have ordered X-ray diffraction equipments for use in their physics laboratories. The metallurgical, geological and other departments will also use the apparatus which will be furnished by the General Electric Co., Schenectady, N. Y., in whose research laboratory the X-ray method of studying crystal structure was developed.

Six similar outfits already are in use in college research laboratories, including Massachusetts Institute of Technology, Rensselaer Polytechnic Institute, McGill University, Pennsylvania State College, University of Wisconsin, and California Institute of Technology. Two industrial research laboratories and two government laboratories also are equipped with this type of apparatus. The General Electric Co. itself is using two sets constantly.

M. H. Medwedeff has resigned as metallurgist and superintendent of tht heat treating department of the Marion Forged Products Co., Marion, Ind., to accept a position with the A. C. Spark Plug Co., Flint, Mich.

Dr. Carl Benedicks, director of the Metallographic Institute of Stockholm, Sweden, will deliver the annual lecture before the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers at its annual meeting, the third week in February, 1925. Later Dr. Benedicks will visit several of the leading universities of the country, as well as some of the local chapters of the American Society for Steel Treating, and deliver addresses.

A bulletin has recently been issued describing a new simplex permeameter which has been perfected by Frank P. Fahy, 50 Church Street, New York. It is described as having several unique features adapted to resistant and research magnetic testing, not only for electrotechnical purposes, but to a like degree in magnetic analysis. Because it was appreciated that a simple instrument for getting at the fundamental magnetic data would assist in speeding up magnetic analysis, a large amount of work has been done in developing this new instrument.

The General Electric Co., Schenectady, N. Y., has appropriated $25,000 for a Steinmetz memorial fund for Union College in memory of Dr. Charles

P. Steinmetz, the company's chief consulting engineer, who died a year ago, President Charles A. Richmond of Union has announced. The income from this fund will be used to provide four scholarships annually.

Students in any of the courses at Union are eligible, but preference will first be given to sons of employees of the General Electric Co. and next to sons of residents of Schenectady.

Hoover Steel Ball Co., Ann Arbor, Mich., has purchased the Imperial Bearing Co. of Detroit. The equipment of the latter plant will shortly be moved to Ann Arbor and housed in the Hoover plant. New machinery and equipment, in addition to that purchased from the Imperial Bearing Co., is being added for the production of ball thrust bearings, roller bearings, and ball retainers. The new program does not include the manufacture of annular or radial ball bearings. The personnel of the company remains the same as before, with H. D. Runciman as general manager. S. A. Strickland, manager of the Imperial plant, will be manager of the bearing division. Mr. Strickland has become a director in place of Mr. Dobson who has severed his connections with the company.

The Carpenter Steel Co., Reading, Pa., announces the opening of an office and warehouse at 633 Fulton Street, Indianapolis, Ind., with a complete stock of high speed steel, carbon tool steel and drill rods, with H. J. Joyce, Jr., in charge.

Marcus A. Grossmann, formerly with Atlas Steel Corp., Dunkirk, N. Y., is now in charge of the newly established research department at United Alloy Steel Corp., Canton, Ohio.

The Central Steel Company, Massillon, Ohio, have recently issued a new handbook entitled, "Agathon Alloy Steels." This booklet gives a description of their various alloy steels and also contains a number of tables of data of interest to metallurgists and engineers.

Shephard Electric Crane and Hoist Co., Montour Falls, N. Y., have published a new book of electric hoists made by the company. It describes each type of floor-operated hoist, illustrates an installation, gives a portrait view of the hoist, clearance drawing and dimensions, and complete information regarding capacities, heights of lift, prices, etc.

It has been announced that the American Museum of Safety, 120 East 28th Street, New York City, is open daily from 10:00 a. m. to 5:00 p. m., and on Saturdays from 10:00 a. m. to 12:00 noon, and the director will be pleased to receive visitors when they are in the vicinity.

Gilbert J. MacQuarrie, for many years connected with the Crucible Steel Co., of America, has been appointed manager of the Boston office of William Jessop & Sons, Inc., New York.

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

TOOL HARDENER would like position in or around vicinity of New York. Has had 11 years' experience. Is able to give A No. 1 references. Address 12-5.

CHEMIST desires position. Technical graduate. 20 years' experience in iron and steel business. Best of references. Address 12-10.

HEAT TREATER desires position. Has had 14 years' experience, being in charge of four different heat treating plants during that time. Address 11-10.

FOREMAN HEAT TREATER desires position as foreman of heat treating plant or service man for steel company. 20 years' thorough practical experience in tool hardening and heat treatment of steel. During last 12 years has had entire charge of steel treating departments for several large manufacturing concerns. Best of references furnished. Address 11-15.

AN OPPORTUNITY to return to the steel game is desired by young man, age 25. 2 years heat treating and inspection on alloy steels, followed by 3½ years in telephone industry, with unusually varied experience and all around training in inspection planning, training, investigation and supervision and methods of engineering. Technical graduate. Married. Has handled 20 men on heat treating and has obtained results in 5 supervisory positions. Plans to develop eventually into sales organization. Now available. Location unimportant. Address 11-35.

FORGE SHOP FOREMAN desires position. Experienced in all kinds of hammer forgings, tool dressing, hardening and carburizing. Can give best of references. Address 11-40.

CHEMIST, METALLURGIST, INSPECTOR, with 12 years' experience in open hearth, rolling mill and laboratory, wants to make permanent connection, where ability and experience will lead to advancement. Familiar with high and low carbon steels. No restrictions as to district. Address 11-45.

FOREMAN TOOL HARDENER OR HEAT TREATER wishes an opportunity to demonstrate his ability. Will consider position as assistant or anything. Formerly in charge of small heat-treating and hardening department. Six years' experience covering chemical analysis, metallography, physical testing, hardening of tool steels, high speed steel and drop forge dies. Expert hardener and can investigate tool troubles. Address 12-20.

POSITIONS WANTED

CHEMIST AND HEAT TREATER desires position in Philadelphia or vicinity. Experienced in heat treatment of low carbon, high carbon and high speed steel; also carburizing, pyrometry, physical testing and inspection; chemical analysis of ferrous and non-ferrous metals. Will accept position as assistant or anything which will show possibility of advancement. Reasonable salary. Address 11-5.

TOOL HARDENER AND HEAT TREATER desires position. 12 years' practical experience covering all phases of heat treating. Fully capable of taking charge of hardening department. Eastern location preferred, but will go anywhere. Address 11-50.

POSITIONS OPEN

WANTED THOROUGHLY EXPERIENCED HARDENER FOREMAN. Must have executive experience and complete knowledge of heat treatment of high speed, carbon, alloy steels and carburizing. Hardening plant is constructed with all modern appliances. State age, experience and salary expected. Address 11-25.

WANTED GENERAL MANAGER of cold-rolled steel and stamping manufactory in New England. Do not apply unless you have mastered and managed both lines, and have been receiving over $10,000 salary a year. Address 11-30.

WANTED tool steel salesman for Detroit territory by one of oldest tool steel firms in business. One acquainted with treating tool steel desired. Very good opportunity. Salary and commission basis. In reply give education, training, experience, married or single. Address 12-15.

WANTED

FOR SALE — ROCKWELL HARDNESS TESTER. Direct Reading No. 2½A with Diamond Cone Point. Slightly Used. Good Condition. Address Keystone Screw Co., Bullitt Bldg., Philadelphia.

WANTED—A used Rockwell hardness tester. Must be in good condition. Address 11-20.

The American Metallurgical Corporation, Industrial Engineers of Boston, have announced the receipt of orders from the following concerns for electric heat treating furnaces: Pratt and Whitney Co., Hartford, duplicate of lead pot furnace; Hookless Fastener Co., Meadville, Pa., one nickel silver annealing furnace; F. N. Burt Co., Ltd., Buffalo, N. Y., one air heater; American Saw and Manufacturing Co., Springfield, Mass., one electric central oil heating system for the tempering of hack saws and band saws; Clayton Manufacturing Co., Bristol, Conn., one heat treating furnace; and DeLaval Separator Co., Poughkeepsie, N. Y., one heat treating furnace.

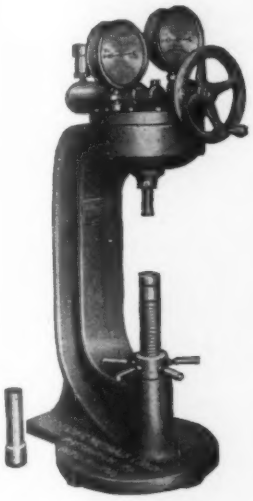
O. T. Muehlemeyer, formerly metallurgist with the Barber-Colman Company, has announced that he will establish a plant for commercial heat treating services with headquarters in Rockford, Illinois. Mr. Muehlemeyer has had many years of experience in both theoretical and practical heat treatment of materials, and is in a position to render helpful service to the industries. His equipment will be thoroughly up to date. Gas fired and electric furnaces will be used exclusively. Hardening of high speed steel in shapes of intricate design will be featured; also general die and tool hardening besides quality carburizing, heat treating and annealing. The plant will be located in that part of industrial Rockford known as "Waterpower" comprising a part of the space formerly occupied by the Rockford Brass Works on Race Street. Mr. Muehlemeyer will also conduct an office for consulting services on thermal treatment and later on, plans to add a chemical and physical testing laboratory.

The Driver-Harris Company have recently accomplished the production of a "Nichrome" plate or sheet, 128 inches long, 57 inches wide, and 3/8 inch thick, weighing about 1,000 pounds, this being the largest plate of an alloy containing a high percentage of nickel and chromium yet produced. When the early difficulties of producing resistance wire and strip of this alloy are considered, the production of a plate of this size can well be appreciated and is considered an event of great commercial importance. There has long been a demand for large sheets, or plates, of high nickel-chromium alloy, but early attempts were so discouraging and expensive that efforts to accomplish these results were abandoned.

Plates of this size should be of great value in the manufacture of certain containers and furnace parts and when perforated as screens for use in chemical sifting and ore roasting apparatus; in fact, in all services where temperatures between 1700 degrees Fahr. and 2200 degrees Fahr. are encountered. Also, where high temperature and chemical resistance is required.

While the production of a plate of this alloy in this size is considered an accomplishment of importance, it has, at the same time, proven with proper size billets, longer plates of the same alloy may be as easily produced. The method of manufacture is that usually used in steel sheet production, except that in the forging, rolling and hot flattening operations, higher temperatures must necessarily be applied to the material.

S. M. Co. Brinell Machine



This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

The Standard Machine Adopted by

American Can Co.
American Machine & Mfg. Co.
E. C. Atkins & Co.
Canadian Fairbanks Morse Co.
Carbon Steel Co.
Carnegie Steel Co.
Chicago Pneumatic Tool Co.
Columbia Steel & Shafting Co.
Curtis Aeroplane & Motor Co.
Dayton Engineering Laboratories
Dominion Steel & Foundry Co., Ltd.
Eagle Pitcher Lead Co.
Firth-Sterling Steel Co.
Henry Ford & Son, Inc.
General Electric Co.
Hughes Tool Co.
Latrobe Electric Steel Co.
Lincoln Motor Co.
Maxwell Motor Co.
McMyler Interstate Co.
Nash Motors Co.
Oliver Chilled Plow Works
Parish & Pool Co.
Piston Ring Co.
Pittsburgh Testing Laboratory
Pollack Steel Co.
Priemier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY

"Everything for the Laboratory"

PITTSBURGH, PA.

The properties of the "Nichrome" composition of which this sheet is composed are well known, but, the following data as to the tensile strength at elevated temperatures and resistance to chemical action, will, no doubt, be of interest and further indicate difficulties which had to be overcome for the successful accomplishment.

ULTIMATE TENSILE STRENGTH AT ELEVATED TEMP.

200 degrees	94,000
400 degrees	91,000
600 degrees	59,000
800 degrees	32,000

RESISTANCE TO CORROSION

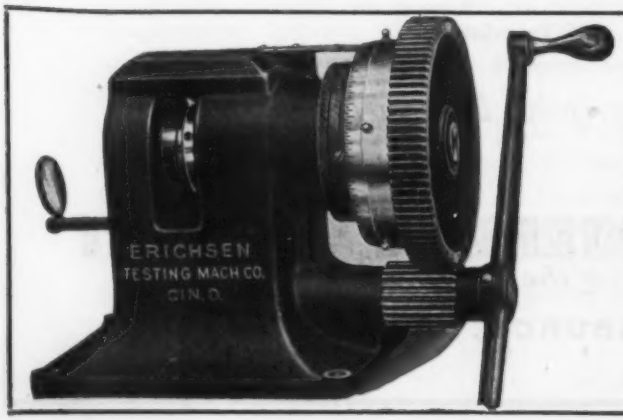
Sulphuric acid at 20 degrees Cent. (68 degrees Fahr.) 125 c.c. acid in beaker—10 gm. sample, 333 hours.

SPECIFIC GRAVITY OF ACID	LOSS IN GMS. SQ. IN. HR.
1.830	.00007
1.747	.00019
1.408	.000
1.142	.000
1.036	.00006

Same conditions at 80 degrees Cent. (176 degrees Fahr.) 71½ hours total 24½ hours at 80 degrees Cent. Balance at 20 degrees Cent.

SPECIFIC GRAVITY OF ACID	LOSS IN GMS. SQ. IN. HR.
1.830	.004
1.408	.0010
1.036	.0004

Nitric acid tests show rather severe corrosion. Not recommended for any concentration of this acid. HCl; action is not severe up to 20 per cent cold acid. Not recommended, however. Sulphurus acid action six times that of 1.830 specific gravity sulphuric acid under similar conditions. The action of Acetic acid is severe. Entirely satisfactory for ammonium hydroxide all concentrations. Entirely satisfactory for lactic acid.



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For the Determination of the Drawing, Stamping, Compressive and Folding Qualities (the "Workability") of Sheet Metals

Know your Metal.
Save time and save money.

The Bock Machine Company
3618 Colerain Ave. Cincinnati, O.

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Transactions of American Society for Steel Treating

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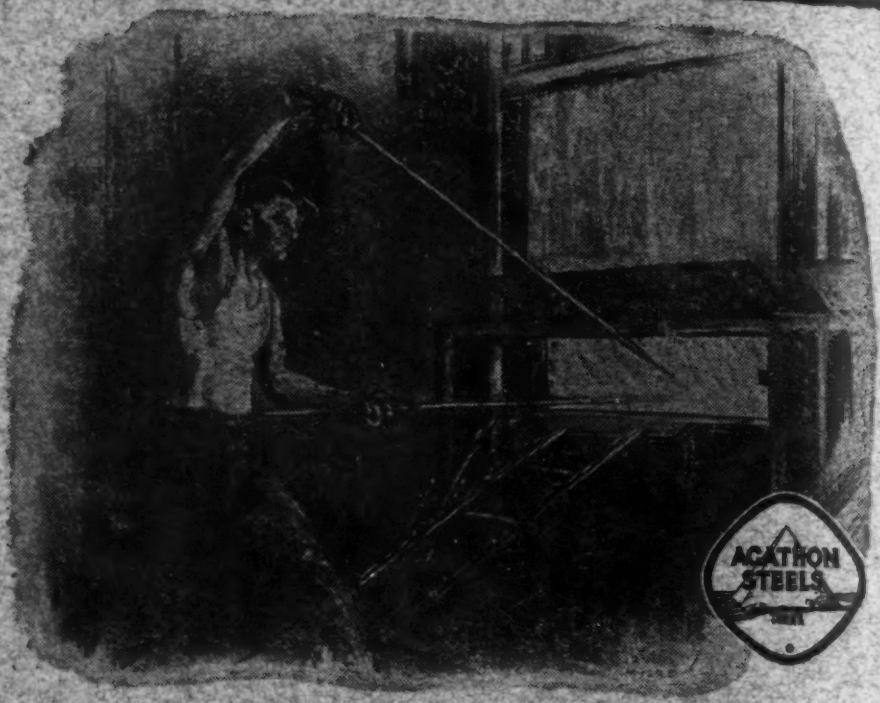

Agathon Sheets Meet Exacting Requirements

THE same precise and careful methods used in the production of Agathon Alloy Steels are firmly established in the production of our sheet mill division. Special open hearth pickled sheet bars are used as raw material and our processes of rolling and finishing are refined to a point capable of meeting the most exacting sheet steel requirements. Write us.

Use Agathon Sheet Steel for

Automobile Bodies
Cowls
Hoods
Crown Fenders
Metal Furniture
Metal Doors and Window Casings
Railroad Car Interiors, Etc.

The Central Steel Company

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AGATHON SHEET STEEL

For Maximum Life

of Tools or Parts

Harden by the Hump Method

GAS FURNACE
Lacks in ***exact*** information

MOLTEN BATH
No control of rate of heating

Ask for a Copy of Catalog 90-S

THE HUMP METHOD
Full control of all factors; quenching, rate of heating, furnace atmosphere

To Assure Full Control of all Factors

From hardening based on approximate information, to exact control by the Hump Method is a most profitable step. It minimizes hardening costs and assures maximum life. Let us supply you with actual figures on the possible saving in your plant.

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LEEDS & NORTHRUP COMPANY

POTENTIOMETER PYROMETERS HUMP ELECTRIC FURNACES

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LOS ANGELES, CALIF.

Looking Backward -- and Forward With Bohnite

This month brings us to the end of 1924. And as we look back over the past twelve months we review the achievements of Bohnite with a fine glow of pride.

Not merely has our volume of business been highly pleasing, but the closing months of the year were marked by the return to us of a greatly valued costomer.

This customer had strayed from the fold, but found that only Bohnite could give him the carbonizing results he had learned to expect from his case hardening compound. So he came back.

Other incidents equally pleasing have occurred, and as we review these past twelve months as well as the past twelve years, we look forward to 1925 with extraordinary confidence.

The Case Hardening Service Company

2281 Scranton Road **Cleveland, Ohio**

Bohnite

It's What You Get Out Of It That Counts

THE

TRANSACTIONS

OF THE

AMERICAN SOCIETY FOR STEEL TREATING

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RAY T. BAYLESS, *Editor*

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Steel Treaters--

Do you know

the proper hardening temperatures and speeds for different steel alloys?

a frequently unsuspected cause for lack of proper hardness?

the most important requirement of a good quenching medium?

the relative values of different quenching mediums?

what single operation in quenching will assure uniform and at the same time will save oil, time and reduce fire risk?

How Ford, General Motors, Packard and Hyatt cool their quenching oil?

All these and many other questions of interest to steel treaters are answered in a treatise on "The Cooling of Quenching Oil in the Heat Treatment of Steel" which has been published for *free distribution* by The Griscom-Russell Company, 97 West Street, New York. You can obtain a copy by writing them.

Reliable and useful hardness information - quickly obtained

A carriage slide is a vital part of every typewriter, and its hardness is a factor of prime importance.

Realizing this the Royal Typewriter Co., of Hartford, Conn., tests the ball races of their typewriters with a Rockwell Hardness Tester. It not only enables them to pass those slides which have been properly hardened, but to make sure that each one placed in their typewriters has just the right hardness to give long and satisfactory service.

That is exactly what the Rockwell does for over half a thousand other companies—it gives them useful and reliable information in plain numbers about the hardness of their work. And it gives that information quickly, too, upon its direct reading dial.

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Catalogue and details of our thirty day free trial offer gladly sent upon request.

WILSON-MAEULEN CO., Inc.

379 Concord Avenue New York City

HEART TO HEART TALK WITH STEEL TREATERS

By the President of
E. F. HOUGHTON & CO.

THERE is something I am certain I have never told you, because I only learned it myself yesterday.

You know I am the President of our Company, and there are many things about the Philadelphia, Chicago and Detroit Plants which I do not do myself, or even supervise personally. One of them is the manufacture of casehardening material.

The other day it became necessary for me to know, of my own knowledge, just how we were manufacturing HOUGHTON'S QUICK-LIGHT CARBURIZER, so I went over to the Philadelphia Plant and studied the operation from start to finish.

I was not surprised to learn that the product was made somewhat differently from what I supposed and what I had witnessed several years back, because our business consists of one continuous performance of evolution of improvements.

I was accompanied by the Production Manager, the Director of Works and the Chief of Research.

When I inquired why the changes, here is the substance of what I was told by Mr. George W. Pressell, Chief of Research and a Fellow of the Society, who acted as spokesman.

"Mr. Carpenter, laboratory tests of carburizers are purely superficial. The practical tests made in our own hardening room mean but little more, when it comes to testing comparative merits of economy, because of the fact that each casehardening material must do service several heats, it being the commonest practice to use a material in-

definitely by reenergizing it with a certain percentage of fresh material each heat. We can tell easy enough what will give the best penetration on the first heat, but beyond that we have not the facilities to test comparative economy, nor would the great expense warrant our doing so. Our materials in the last analysis must be tested out in the works of neutral customers, interested with us in the improvement of caseharden-ing product. Then we must make the changes slowly, because of the enormous loss any radical change might cause, were it to deteriorate instead of improve our product. Therefore, the changes which you notice have not been sudden, but have been made over a period of several years.

"You will realize that if a casehardening material is radically altered on the first heat, on the second the work will lack uniformity. One of the greatest causes of deterioration of quality of a casehardening material, is the dusting off of the surface, of the energizer, both in transit and in service, particularly in the first heat. Of course the cohesiveness of the surface of the charcoal grain, to which the energizer is attached, is the principal factor in preventing the energizer dusting, but the quantity and quality of the binder used are also important factors. If you use an excess quantity of binder, the charcoal grain absorbs it, and this adds to the weight, clogs the pores, and lowers the thermal conductivity. By destroying the porosity the carbon gas producing strength of the charcoal is decidedly lessened. As you now see QUICK-LIGHT "A" being produced, you see the lightest in weight and the strongest grain casehardening material thus far made by anyone."

I was glad to know all this and I hope you are.

Yours fraternally,

CHAS. E. CARPENTER,

President of E. F. Houghton & Co.

P. O. Box 6913
Philadelphia, Pa.

Accuracy and Dependability are *all-important*

You can achieve both by employing

R&H CHEMICALS

in your surface hardening bath

R & H Case Hardener (30%)
Special Case Hardening Mixture 45%
Cyanide Chloride Mixture 73/76%

One or all of these compounds will meet ***Your*** needs

If equipped to make up your own mixture use as a basis

CYANEGG R&HCCo TRADE MARK

Cyanide Sodium 96/98%
guaranteed 51/52% cyanogen
equivalent to 128/130% Potassium Cyanide

Technical assistance rendered to users without extra charge

***The* ROESSLER & HASSLACHER CHEMICAL CO.**
709 Sixth Avenue **NEW YORK**

Nichrome

TRADE MARK REG. U. S. PAT. OFF.

Serves Steel Treaters In Two Ways

In Producing Heat—

Nearly 20 years of proven dependability have made "Nichrome" wire, ribbon and strip the standard of comparison in electric heating element performance throughout the world.

For "Nichrome" performance in electric furnaces, ovens, etc., you must have "Nichrome" in the heating elements —"Nichrome" IV for the higher temperatures. Specify *** "Nichrome—the Driver-Harris resistance alloy."

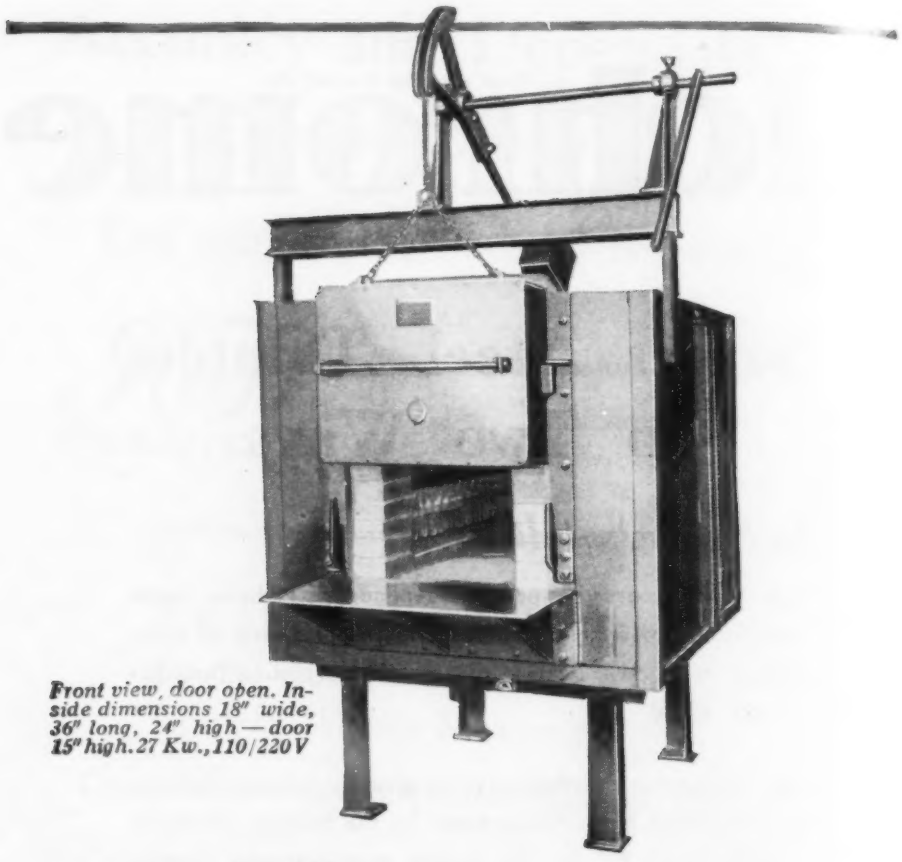
In Resisting Heat—

Specific and authentic data pertaining to "Nichrome" in the form of Castings for carburizing and other high temperature work are given in a new 120-page book:—Also a treatise of carburizing and case-hardening fundamentals. The name of the book is "Driver-Harris Co. Castings—Made and Sold under the Trade Mark 'Nichrome.'" FREE—if you have not already received a copy.

DRIVER-HARRIS COMPANY

HARRISON, NEW JERSEY

CHICAGO — DETROIT ENGLAND — FRANCE



Front view, door open. Inside dimensions 18" wide, 36" long, 24" high — door 15" high. 27 Kw., 110/220 V

Electric Heat—

Direct to Charge

In this G-E Direct-Heat Furnace—the heating unit, located in the furnace chamber, radiates its heat directly to the charge.

This type of heating unit responds more quickly to automatic control and operates at lower temperature for any given temperature in the furnace chamber than any other type—insuring long life.

The G-E Direct-Heat Furnace is used for heat treating tools, for heat treatment research in the laboratory, and for many other heat treating processes up to 2000° F.

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Schenectady, N. Y.
Sales Offices in all Large Cities

GENERAL ELECTRIC

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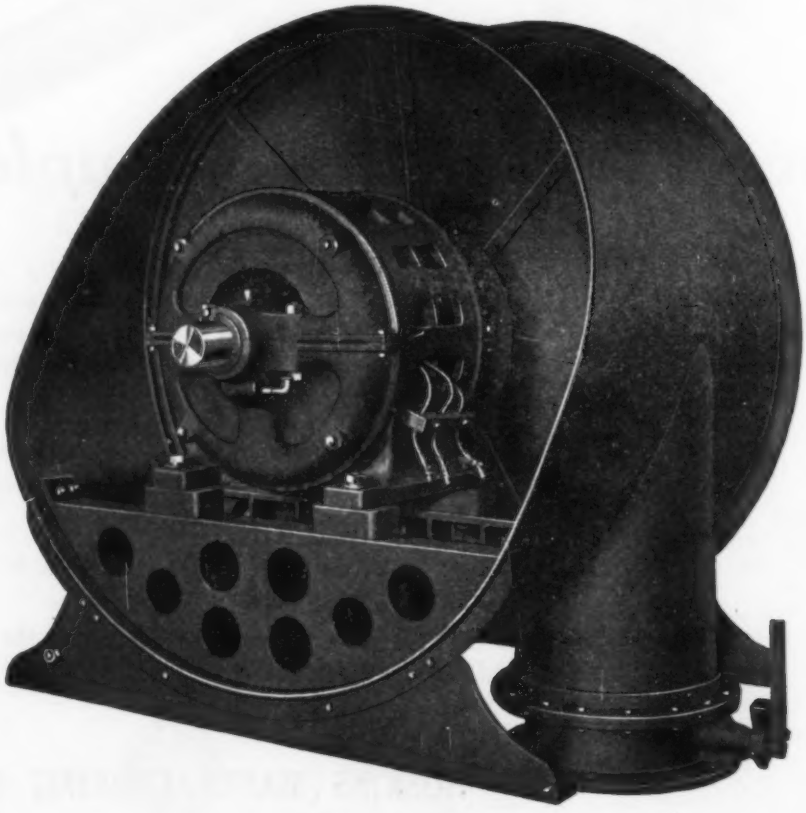

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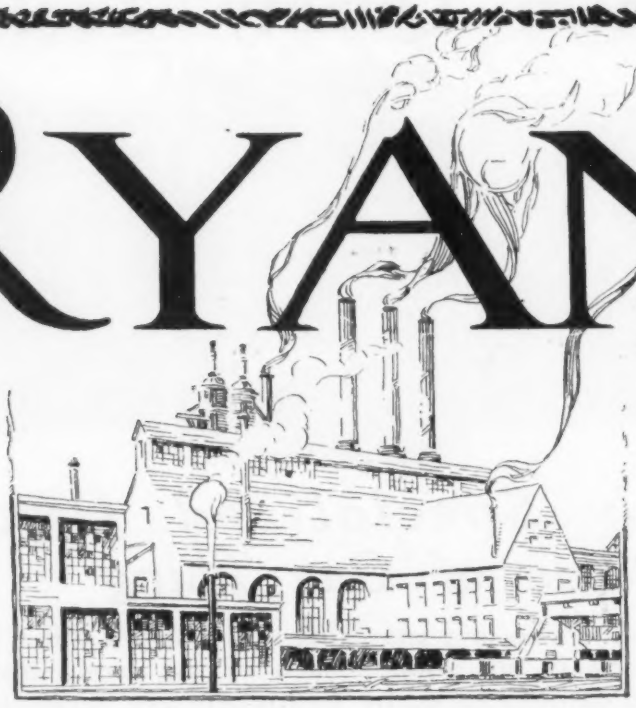

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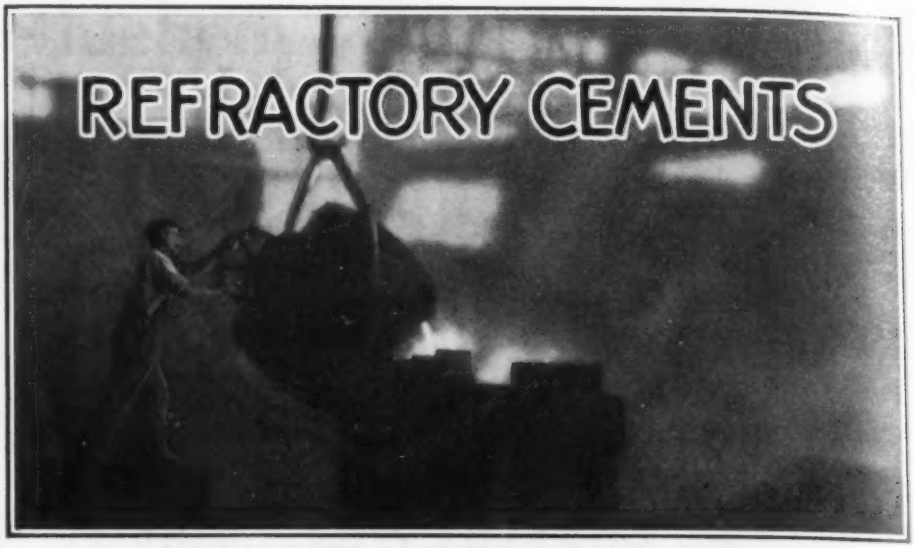

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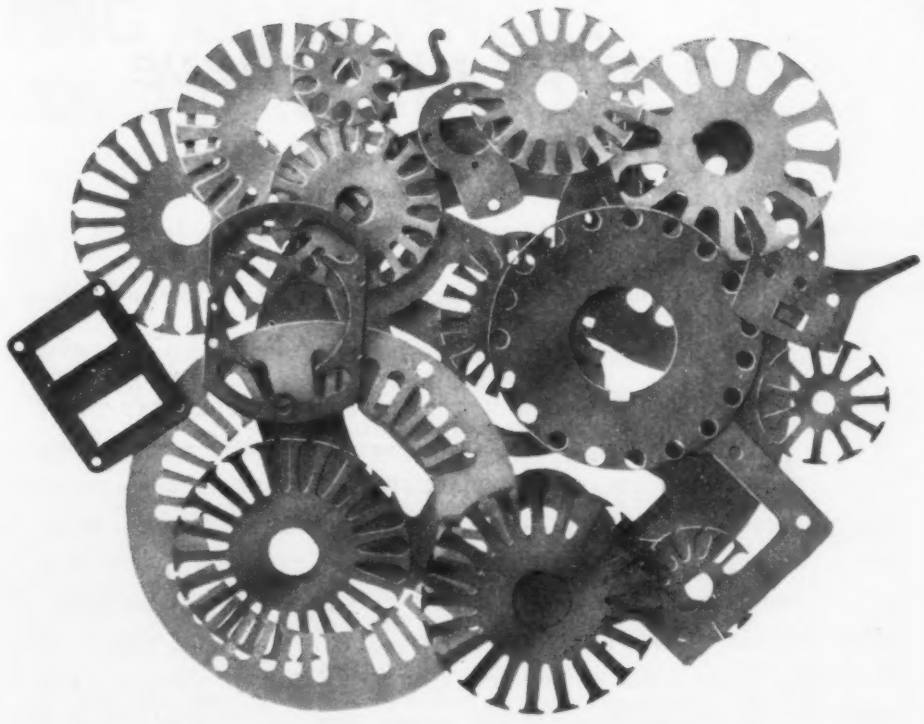

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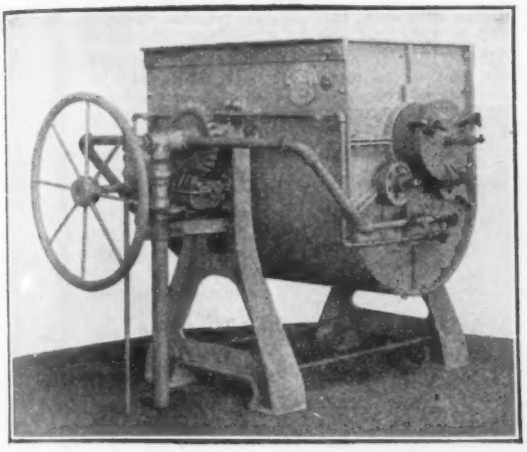

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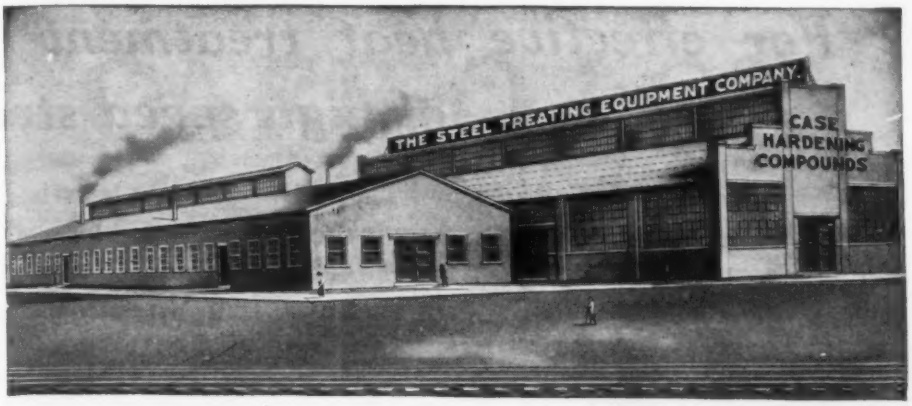

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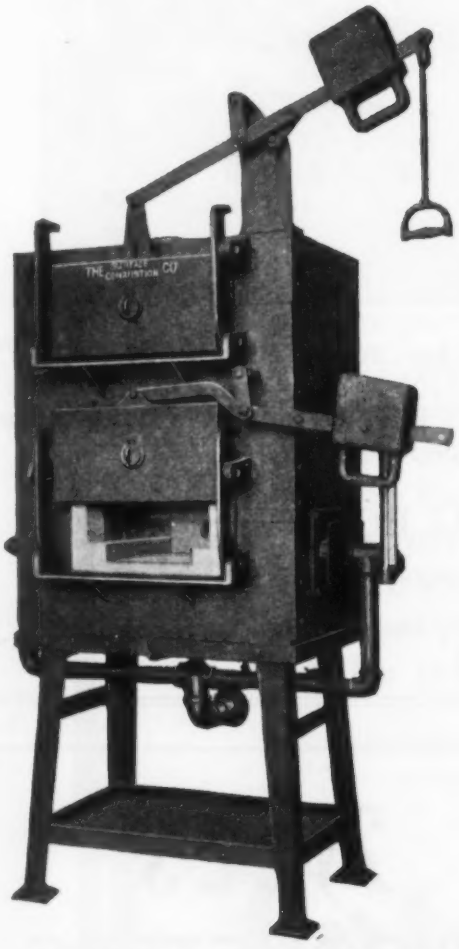

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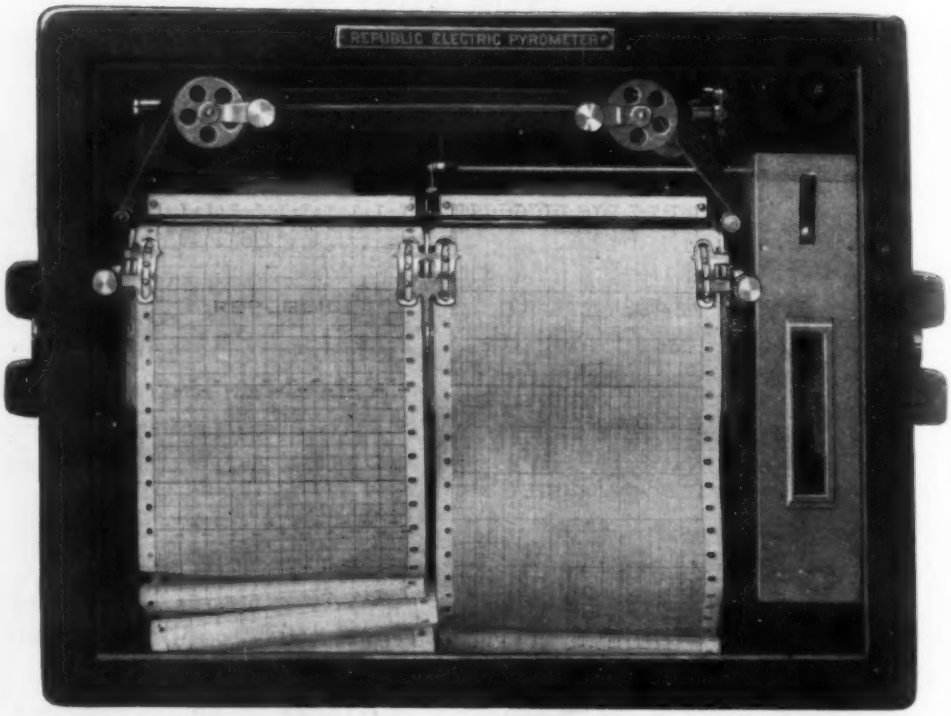

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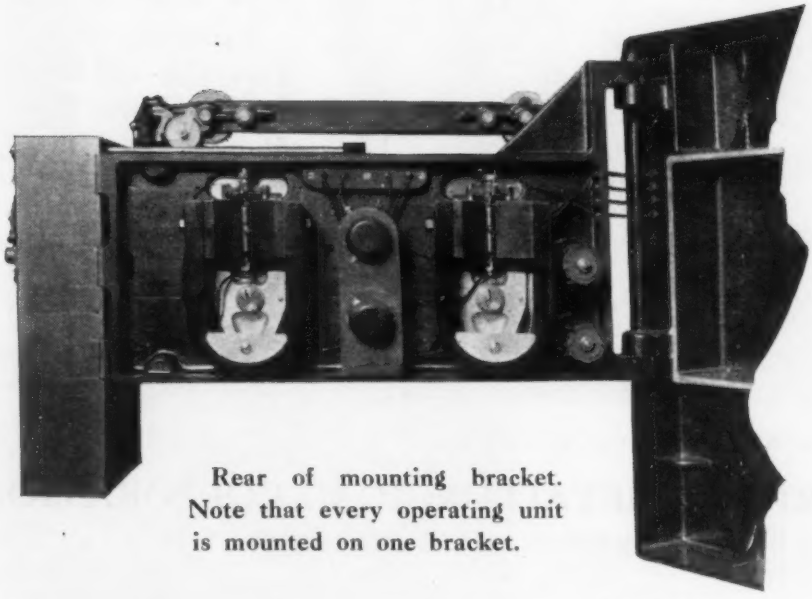

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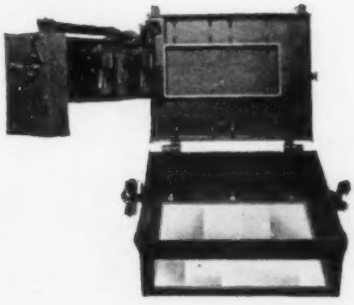

Recorder showing front dropped down and mounting bracket swung open.

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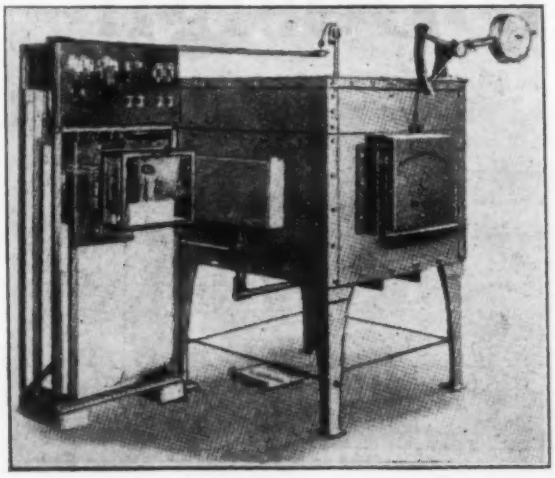

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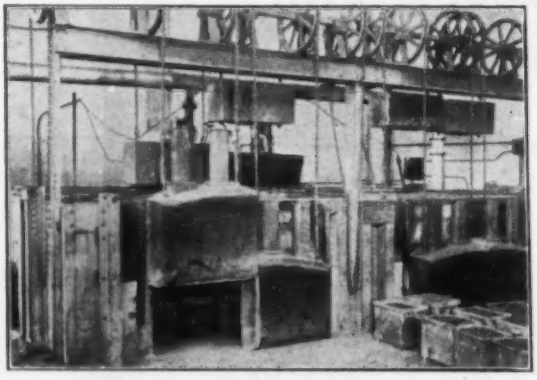


Built-in Double Chamber Carbonizing Furnace

F. J. Goodenow Furnace Co.

DESIGNERS AND BUILDERS OF

INDUSTRIAL FURNACES

FOR ALL PURPOSES AND ALL FUELS

Functional efficiency and freedom from repairs our strongest claim upon our customers.

255 Meldrum Ave. Detroit

ZIV'S "WIZARD"

UNBREAKABLE TOOL STEEL

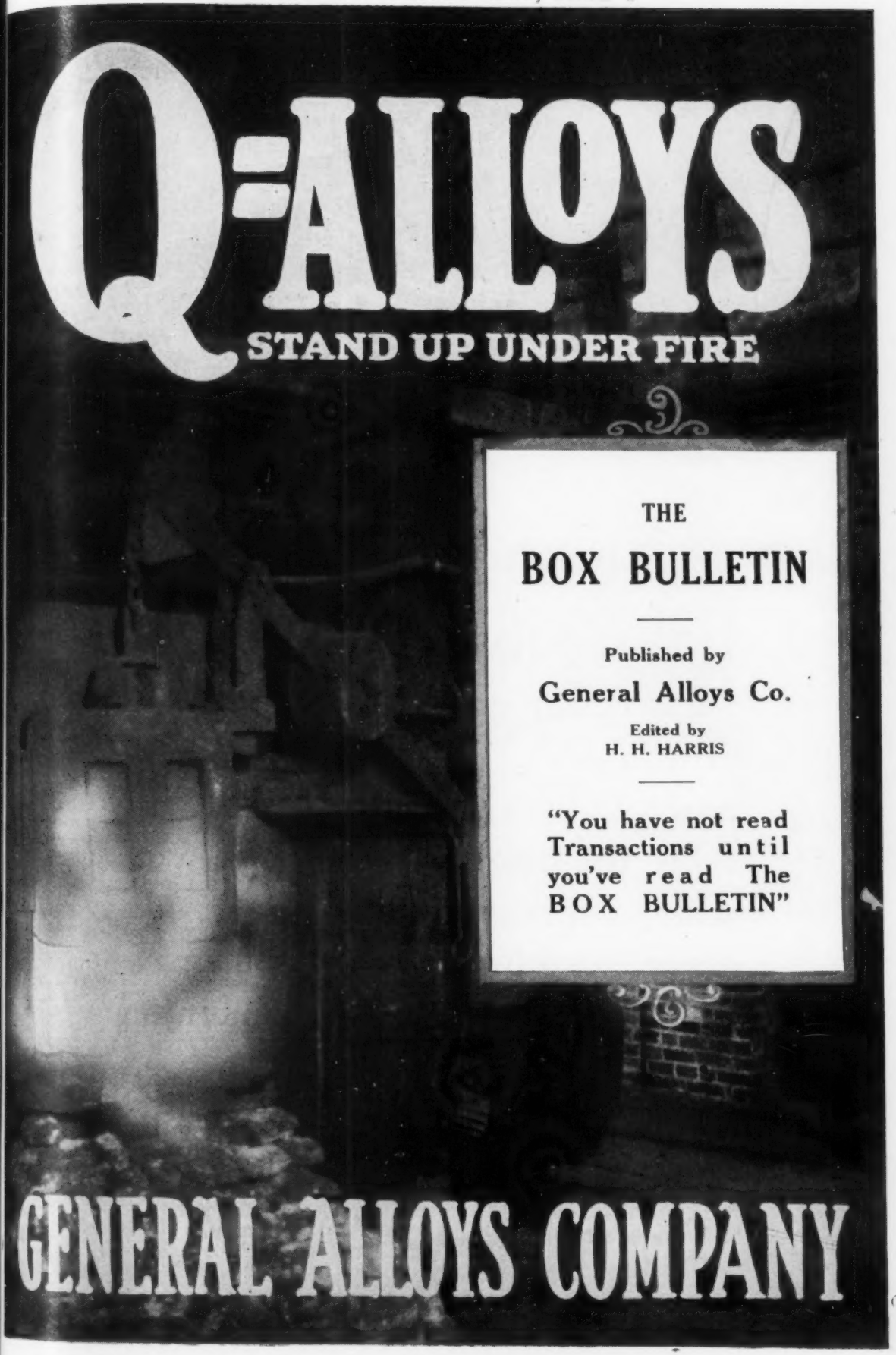
After tempering, this point was bent cold, several times both ways without breaking.

Especially Adapted for
Pneumatic Tools

ZIV STEEL & WIRE CO., 4423 W. Kinzie St., Chicago

Q=ALLOYS

STAND UP UNDER FIRE



THE

BOX BULLETIN

Published by

General Alloys Co.

Edited by
H. H. HARRIS

"You have not read Transactions until you've read The BOX BULLETIN"

GENERAL ALLOYS COMPANY

BOX BULLETIN SUPPLEMENT, PAGE II

Christmas Greetings!

May this Christmas be for you one of glory and gladness! May true happiness come to those most dear to you! May the incoming year greet you with prosperity in abundance! May every dawn bring with it some new delight for you! May every morning add to your joys, and every evening bring you peace and contentment!

General Alloys Company

BOSTON

CHRISTMAS 1924

BOX BULLETIN SUPPLEMENT, PAGE III

$$$ Merry Xmas-Happy New Year $$$ U. S. A.

The Election was settled to the satisfaction of the majority of voters, and certainly to the advantage of American Business in general. Last week, the New York Stock Exchange did its record business in 136 years! Large Corporations have changed hands bodily, in some cases over 90% of the Common stock being purchased by new and larger interests at top-notch prices. Brokerage profits for the week of November 10th are estimated at $40,000,000.00 in New York alone.

The Farmers are emerging from the "Slough of Despond" and are again taking their place as a large buying unit. Crops promise to establish records in many sections, and are increasing in value at the rate of several Million dollars per day. Farm loans will be paid, and "new" money will be released to aid Industry and building.

Buildings, factories, and homes are under construction at a rate which not only insures the building trades, and their labor group, steady employment through the winter, but also promises lower rents and better homes.

The Purchases that were not made last summer will be made next spring, or before. The orders that over-conservative buyers have been holding up, are now being released, and many of them have propagated at an amazing rate while on the shelf. Business is good, and getting Better.

Capital and labor are employed profitably. Every Burg in America is bound to be Busier, Bigger, and Better, in spite of its Chamber of Commerce.

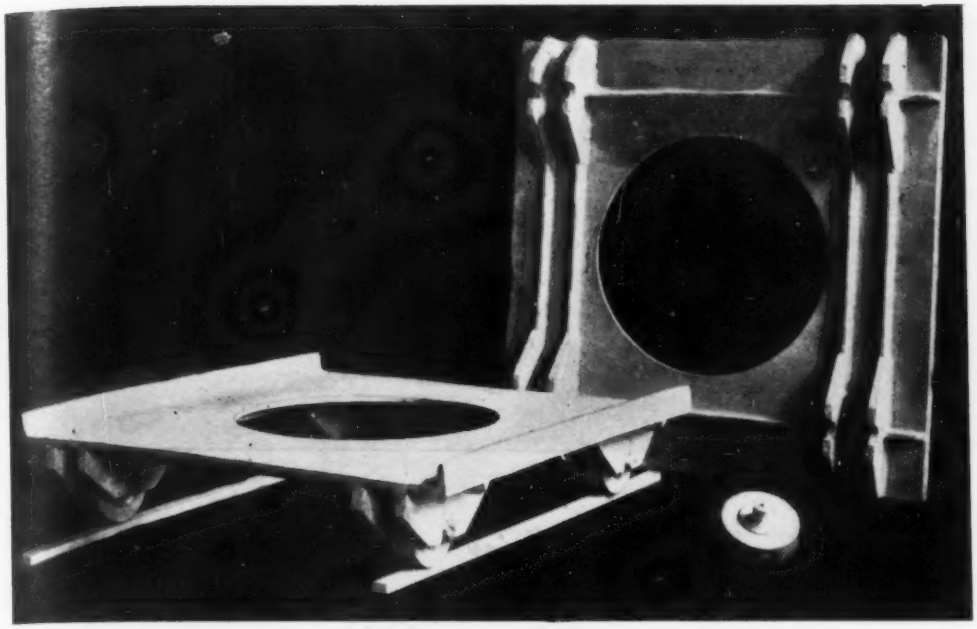
Yea, Brethren, America is in for a Merry Christmas, and a Happy, Prosperous New Year.

KRIT. IKLEPOINT.

BOX BULLETIN SUPPLEMENT, PAGE IV

THE BOX BULLETIN

As I pause from press of business to pen this idle ryme, I am taking "Inventory," for it's inventory time. But it's not the stock I'm checking, nor dollars lost or won that concern me in accounting when the final statement's done. I am thinking of the "life" I've spent, the things I've done and said, the things I can not figure in the black, or in the red. I am thinking of the men I've met in plants thruout the land Who've given of their time to me, held out a friendly hand, Who placed a certain confidence in statements that I made, and staked their judgment on my claims, and on the game I played. I am thinking of the fellows who have gone out of their way to help me put my stuff across,—they do it every day! I see friendships that are ripening, that have stood the test of years. Have I kept faith with those who trusted,—or am I in arrears?. What are dollars, few or many, to record commercial strife, when checked against the finer things along the path of life? In intercourse with fellowmen, the give and take of trade, the profit of enduring worth is not the dollar made. I am humble, as I contemplate how little I can say or do to show that I appreciate what Men, one may be you, have done to aid me on my way.



A Safe Buggy for a Hot Baby

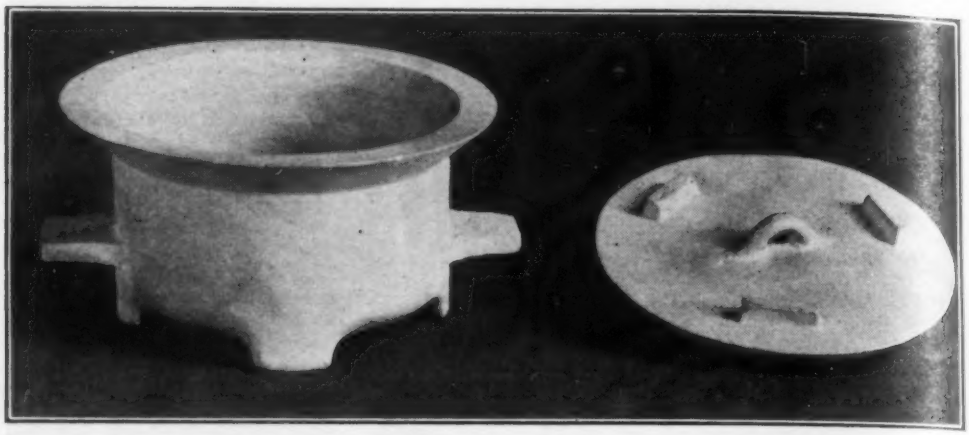
THE increasing tendency to put everything possible on wheels, thus facilitating movement, has not been without sponsors among furnace builders.

The Furnace Truck shown above is part of the conveyor equipment of a novel and efficient electric car type furnace designed and built by the American Metallurgical Corporation, for a representative New England manufacturer. The "Car" platform is cast in one piece of Q-Alloy. Its simple construction is clearly shown. The wheels are cast integral with individual axles from the same material. Rails are also of Q-Alloy.

We can supply dependable car, roller, chain, cam, or screw type conveyor apparatus for practically any type of Steel Treating or Ceramic furnace.

We can also supply Carbonizing, or Annealing Boxes, equipped with wheels or runners for use with Tunnel type furnaces.

BOX BULLETIN SUPPLEMENT, PAGE VI



Fine Pots for Fine Work

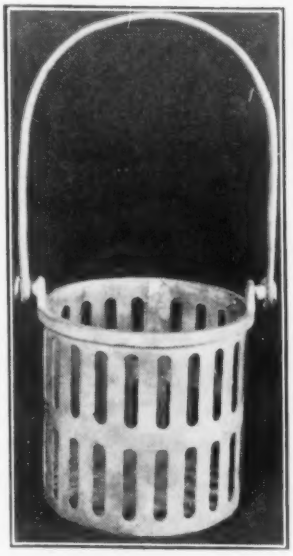
DIES, used in the manufacture of Watch Cases, require careful and scientific heat treatments. They are often engraved with delicate scroll work, and must maintain edges so sharp that stampings made from them compare in sharpness of line with the finest hand engravings.

These dies can not be allowed to scale. Neither can they be heated in salts which cling to the engraved surfaces. Packing in Q-Alloy Pots has been a happy solution. The pot shown above from an untouched photograph is typical of Q-Alloy pots of various sizes used on one job.

Take a good look at this pot. It weighs about 5 lbs. It is cast to an accuracy of .02", and is clean enough to cook in. (We came near photographing it full of Boston Beans.) Compare this casting with the best castings made by our contemporaries, and you have one of the reasons why the leading industrial concerns are standardizing on Q-Alloys.

Maybe you make Tractors, Looms, Roller-Skates, or Lawn-Mowers. If you do you can Heat Treat them more uniformly at a lower cost with Q-Alloy equipment.

Cyanide Baskets of Q-Alloy Sheets

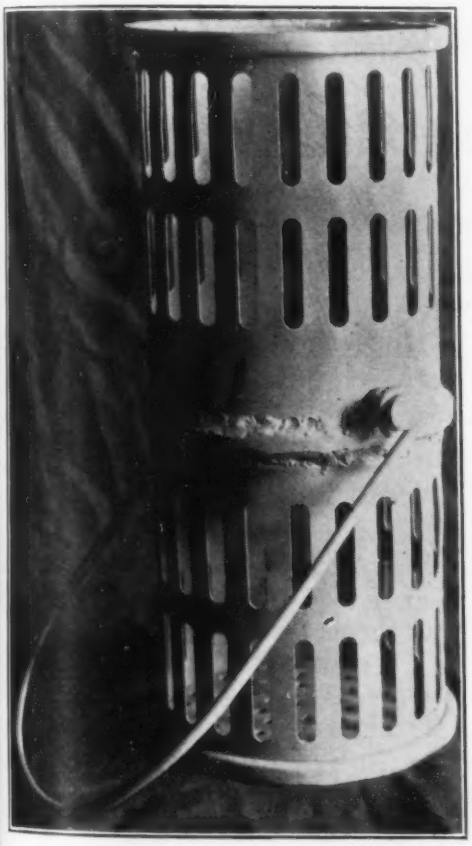


A few months ago we announced in these pages that Q-Alloy Dipping Baskets, fabricated from die cut Q-Alloy sheet were available, at a lower price due to economies in production. Leading Users in all parts of the country have adopted them generally, and we have added several new designs of bails and handles.

THESE BASKETS ARE:

1/2 weight of wire baskets } Lower in cost than either
1/3 weight of cast baskets } cast or wire alloy baskets

The first hand made Q-Alloy sheet baskets have been in service more than three years without a failure.

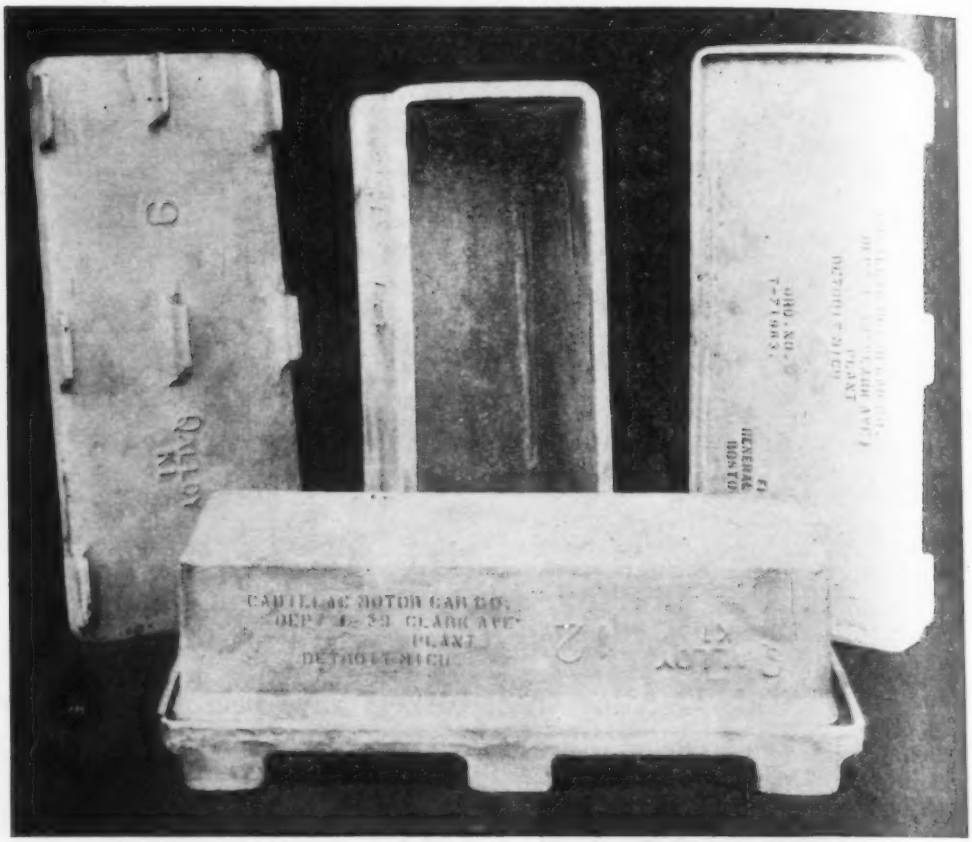


Q-Alloy sheet baskets are approx. 1/16" thick rolled Q-Alloy Sheet, die perforated. They are made with various types of bails or handles as required.

The Baskets shown here are provided with cast bottoms, and reinforcing rings, and with drawn Q-Alloy wire handles. The lower one is of the "Roll-Over" easy dumping design.

These baskets are so light that they greatly reduce the "nonproductive" load in your pots. They carry a minimum of cyanide from the pot. In one plant they have reduced basket cost 76%.

BOX BULLETIN SUPPLEMENT, PAGE VIII



Inverted Carbonizing Boxes

INVERTED Carbonizing Boxes have many advantages. True, they are not the easiest boxes to pack, but they insure a uniformity of heating that is impossible with covered type boxes in the average furnace. Most furnaces are considerably hotter at the top than near the floor of the heating chamber. Frequently covers of boxes become red long before the boxes. The combustion of escaping gases around the edge of the cover may increase the temperature. Maximum temperature is at the weakest part, (the open top) of covered boxes.

The inverted box conducts and distributes excess or uneven heat from top downward. It is physically stronger. It retains gas, and distributes it better. Its weight rests on its sealing surfaces.

One of America's leading Metallurgists has sponsored and developed inverted boxes for several years, in the largest plant devoted to the manufacture of high priced automobiles in the world. Several hundred Q-Alloy Boxes, exclusive equipment, are proving his theories in practice and turning out a product of unsurpassed quality.

BOX BULLETIN SUPPLEMENT, PAGE IX

In Fairness to Yourself
You Ask Them!

When your Boss asks you, "What is the best Heat Resisting Alloy" he wants facts; not hearsay, not what you have read in our "ads" or our competitor's. Can you give him FACTS?

Advertising, any advertising, all advertising, is apt to be biased, for it is written by Manufacturers about their own product. You too would favor your own "Child." We're all human.

Don't take our word about Q-Alloys, don't judge us by our fine showing at the Shows, but *get the facts, yourself,* from Q-Alloy users. Ask them about Q-Alloys, but also about us, our service, and our policy.

If you use heat treating containers, if you have a legitimate interest in Q-Alloys, and write us on your letterhead, we will give you the names of a number of our largest customers, among the largest industrial concerns in the world, who have bought repeat orders of Q-Alloy Castings, over a period of years, totalling hundreds of thousands of dollars. These concerns not only bought Q-Alloy years ago, but they are buying it in increasing quantities today, with orders running into 1925. They made October the best month in the history of this Company, and then exceeded it by 20% in November.

We will refer you to concerns who have not only used Q-Alloys extensively for years, but who have thoroughly tested all "established" competitive alloys. That's important too.

Don't dabble around with "tests." Other concerns have done that for you on a larger scale at great cost, and loss, to them. Write us and we'll give you their names and rest our case on their testimony.

Write Right Now and We'll Write Right Back.

Q-ALLOYS

Most Economical and Efficient Materials

For CARBONIZING BOXES
ANNEALING BOXES
CYANIDE AND LEAD POTS
FURNACE PLATES
MUFFLES AND RACKS
TUBES AND RETORTS
CONVEYOR FURNACES
GLASS ROLLS AND DIES
ANY PARTS

operating between 1000° F. and 2200° F.

GENERAL ALLOYS COMPANY

BOSTON—27—MASS.

CHICAGO
122 So. Michigan Ave.

BOSTON
168 Dartmouth Street

NEW YORK
26 Cortlandt Street

DETROIT
General Motors Building

CLEVELAND
2281 Scranton Rd.

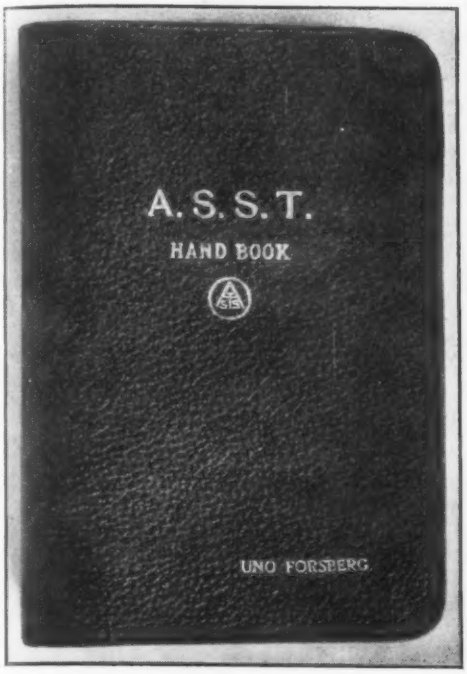
INDIANAPOLIS
Merchants Bank Building

ROCHESTER
921 Granite Building

TORONTO
191 Adams St.

ST. LOUIS
1517 Olive St.

When answering advertisements please mention "Transactions"



ORDER NOW!

DATA SHEET BINDER

The binder shown here is of genuine cow hide, with $\frac{7}{8}$ inch rings, capacity 200 sheets and pocket in cover, especially made for A. S. S. T. Hand Book sheets.

Do not lose your valuable sheets by not having the proper binder.
Members may obtain this binder, with name (in gold) stamped on cover for **$2.00.**

Send order and check to

American Society for Steel Treating
Cleveland, Ohio

DATA SHEETS

The following data sheets have been issued and sent to members. New members desiring back sheets may order all or any sheets desired at the "rate to members." Members will receive free data sheets as issued during the period of their membership.

Send all orders to A. S. S. T., 4600 PROSPECT AVE., CLEVELAND, O.

	Page No.	No. Sheets	Cost to Members	Cost to Non-Members
Nitrogen in Steel	A3-4	1	$0.05	$0.10
Melting Points of Chemical Elements Fusing Points of Seger Cones	A5 A6	1	.05	.10
Decimal and Metric Equivalents of Parts of an Inch	A7-10	2	.10	.20
Specific Heat of Air	A11-14	2	.10	.20
Weights of Steel Bars	A15-22	4	.20	.40
Temperature Conversion Table	A23 and 24	1	.05	.10
Iron Carbon Diagram	A25-38	7	.35	.70
Tungsten as An Alloying Element in Steel	I1-4	2	.10	.20
Recommended Practice in the Heat Treatment of 18% Tungsten High Speed Steel	M3-4	1	.05	.10
Recommended Practice in the Heat Treatment of Plain Carbon Tool Steel	N3-6	2	.10	.20
Pyrometry	S3-17	8	.40	.80
The Preparation of Metallographic Specimens	T3-6	2	.10	.20
Etching Solutions for Iron and Steel and the Structures Revealed by Each	T7-22	8	.40	.80
Photomicrography	T23-38 Incl.	8	.40	.80
Brinell Hardness Test	V1-2	1	.05	.10
Rockwell Hardness Test	V3-5	2	.10	.20
Scleroscope Hardness Test	V7-10	2	.10	.20
Percentage Reduction of Area for Tensile Test Specimens	V11-16 Incl.	3	.15	.30
Standard Clay Fire Brick Shapes and Tables for Turning Diameters With Standard Fire Brick Shapes	W1-20 Incl.	10	.50	1.00
Lead Baths	W21-35 Incl.	8	.40	.80
Fuel Consumption and Heat Losses	W37-42 Incl.	3	.15	.30
		78	$3.90	$7.80

With a maximum temperature between 1700 and 1725 degrees this Hi-Tempo box ran 1200 hours and was still good for additional hours but for the fact that the short legs had worn so low that the dolly would not slide under the pot.

We have seen a Hi-Tempo pot run in lead 1300 hours, and while these results necessarily vary with the conditions, the general average is safely above 1000 hours.

And remember that Hi-Tempo costs only a fraction more than ordinary iron or steel. Moreover, there is always a saving through infrequent replacements as against so many reorders and receiving so many shipments.

Hi-Tempo has been on the market for so many years and used in so many plants that its endorsement as a heat resisting metal is widespread—so much so that the use of it has spread to galvanizing boxes, annealing boxes, hearth plates, furnace bottoms and dozens of other uses.

Use Hi-Tempo wherever there is heat is the answer to your question as to whether you need Hi-Tempo. Send us specifications of the castings you are now using in contact with heat. We will be able to show you economy beyond your ordinary expectations.

Use

The Case Hardening Service Company
2282 Scranton Road
Cleveland, Ohio

Bell & Gossett Company
117 North Dearborn Street
Chicago, Ill.

Hi-Tempo Metal

Wherever There Is Heat

OIL BURNERS
FAN BLAST TYPE

OPERATES ON AIR AT 6 to 10 OUNCES PRESSURE.

NO SMALL ORIFICES
EASILY CLEANED
PERFECT ATOMIZATION
VERY LITTLE NOISE

You will be surprised at the results this burner will give with such low air pressures.

Air controlled by the lever and oil regulated by a special needle valve shown in the illustration.

Cast iron funnel and yoke recommended for holding burner against furnace side plate.

HIGH PRESSURE BURNERS are UNNECESSARY—Give one of these fan blast burners a trial. We will send one for you to test and satisfy yourself—pay for it after you are satisfied with its operation.

Tate-Jones & Co. inc.

Furnace Engineers **Established 1898**

PITTSBURGH, PA.

New York — Detroit — Buffalo — Philadelphia — Chicago — Dayton — St. Louis

When you want tool steel you want the best and usually want it quick.
That's why we have developed a complete distributing organization comprising warehouses, amply stocked with a complete line of RED CUT SUPERIOR and other VASCO TOOL STEELS, all conveniently located in production centers, and numerous branch offices, all in charge of experienced sales engineers insuring unsurpassed quality and service.

Why don't you take advantage of this service and these distributing facilities? No matter where you are located there's a Vasco Warehouse and Branch Office waiting to serve you.

DISTRICT OFFICES:
New York Boston Pittsburgh
Cleveland Dayton Cincinnati

WAREHOUSES:
Latrobe Chicago Springfield, Mass. Detroit

DISTRIBUTORS:
Abegg & Reinhold Co., Los Angeles, Cal.
Peninsula Iron & Steel Co., San Francisco, Cal.
W. S. Dunlap, St. Louis, Mo.
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AGENCIES:
W. S. Murrian Company, Knoxville, Tenn.

VANADIUM ALLOYS STEEL CO.
LATROBE, PENNA.

Is your plant equipped to burn heavy fuel oil, and in this way save 46% on your monthly fuel costs?

There is roughly a difference in cost of 40% between heavy 20° fuel oil and light 32-36° fuel oil.

You also secure 6% more B. T. U. when purchasing heavy oil on a gallon basis.

THE HAGAN HEAVY FUEL OIL BURNER

with the oil return connection at the Oil Head has proven to be the only satisfactory burner for burning low gravity fuels.

Full particulars furnished on request.

George J. Hagan Company

Furnace and Combustion Engineers

Pittsburgh, Pa.

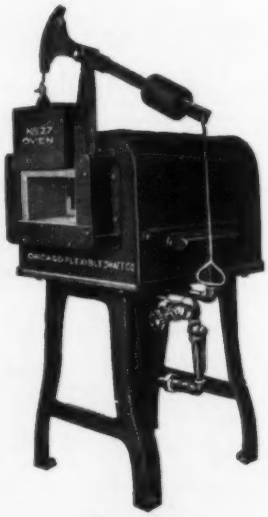
New York Chicago Detroit San Francisco

STEWART

Industrial Furnaces are the result of over 35 years of conscientious effort to build Industrial Furnaces that are most satisfactory.

There are over 150 standard types and sizes that cover practically every phase of heat-treating as well as many specials built without pattern charge.

Send for catalogue 85.



STEWART

No. 27 Oven Furnace for heat-treating carbon steels.

Openings 6" x 12"
Depths 18"
For gas or oil.
One of many sizes.
A size for your requirements.

It pre-heats—while it heats

STEWART

No. 1 Double Deck Furnace.

Opening 5" x 9"
Depth 13½"
For gas or oil
Built in 5 standard sizes.

STEWART

Industrial Furnaces

Chicago Flexible Shaft Company

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943 Granite Bldg., Rochester, N. Y.
608 Kerr Bldg., Detroit, Mich.
306 Sycamore Street, Cincinnati, O.
1738 - 19th Street, Milwaukee, Wis.
1200 - 1201 Standard Life Building, Pittsburgh, Pa.
310 Wesley Bldg., Philadelphia, Pa.
79 Milk Street, Boston 9, Mass.
2024 Railway Ex. Bldg., St. Louis, Mo.
768 Mission Street, San Francisco, Cal.

Canadian Factory,
349 Carlaw Ave., Toronto, Ont.

MIDVALE
INGOTS

A good forging cannot be made from a poor ingot. Midvale ingots are scientifically proportioned to give the most good metal for the least ingot weight.

THE MIDVALE COMPANY
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STEEL TREATERS appreciate the penalties for being

"PENNY WISE and POUND FOOLISH"

OIL TEMPERED

HARD and TOUGH

HY-TEN

There are less expensive steels than HY-TEN but ultimate costs on finished parts continually prove its economy in the long run.

WHEELOCK, LOVEJOY & CO., Inc.

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HEAT TREATED PRODUCTS OUR SPECIALTY

Heppenstall Forge & Knife Co.

WORKS:
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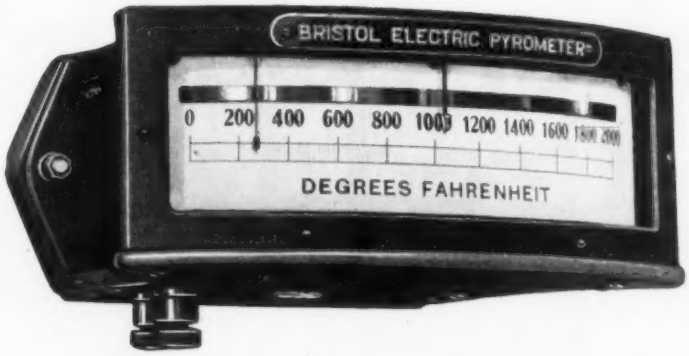


A New And Better PYROMETER

Higher Resistance MOVEMENT

Wide Easy To Read SCALE

TRADE MARK
BRISTOL'S
REG. U.S. PAT. OFFICE

This is the latest achievement in pyrometer equipment. An instrument superior to anything we have previously brought out.

It is a pyrometer that can be easily read at a distance. The scale is 7 inches wide and furnished with combination pointer having a broad section for distance reading and a knife blade section for close-up work. The scale is also provided with a mirror, which prevents any possible error in reading due to paralax.

A high resistance milli-voltmeter movement is used for the measuring element, which is equipped with an accurately balanced moving coil and pointer. It is extremely sensitive, having resistance of 15 to 20 ohms per millivolt. Well damped, making it dead beat in operation.

The usual cold-end error is automatically eliminated by Bristol's Patent Automatic Internal Cold-End Compensator.

Enclosed in a case of aluminum of dust-proof construction. Can be used for wall or switchboard mounting. A small adjusting screw on outside of case provides an easy means of adjustment. This instrument can be furnished for all ranges up to 3000° F.

Ask for Bulletin No. AG-330, giving complete description.

The Bristol line includes Recording Pressure Gauges, Thermometers, Pyrometers, Psychrometers, Voltmeters, Ammeters, Wattmeters, Milli-voltmeters, Shunt Ammeters, Frequency Meters, Time and Motion Recorders, also Temperature Control Equipment.

THE BRISTOL COMPANY

Waterbury, Conn.

Branch Offices:

Boston
New York
Philadelphia
Pittsburgh
Detroit
Chicago
St. Louis
San Francisco

Anchor Cold Drawn Products

High Speed Drill Rods
Carbon Drill Rods
Cold Drawn Tool Steels
Cold Drawn Alloy Tap Steel
Cold Drawn Special Shapes
Cold Drawn Special Analysis Steels

Anchor Drawn Steel Co.
Latrobe ~ Pa.

For economy and efficiency you will find no better product than our "SEMENTITE" Casehardening Compound.
For surface hardening there is nothing better than SHUR-CASE.

Heat Treating Supply Co.
Sandusky, Ohio

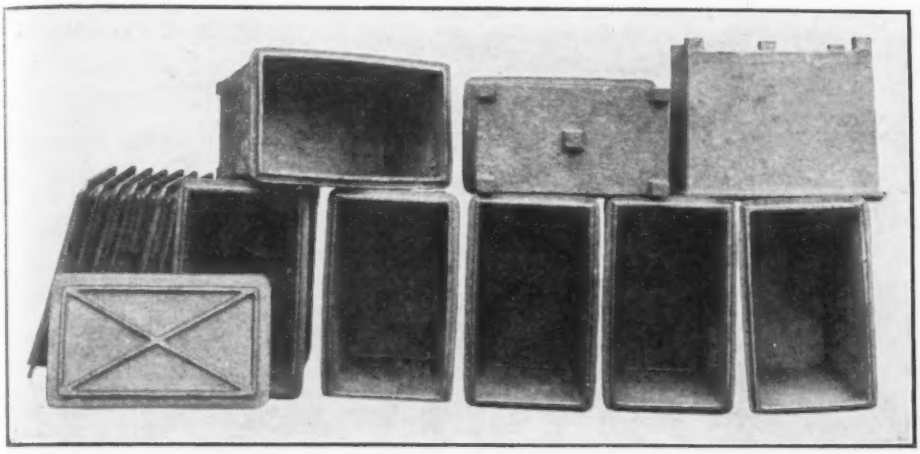
FLAT TIRE!!! RADIATOR BOILING!!! NO GAS, OIL LOW!!

Suppose all this happened at once and you went to the filling station and all they had was oil! and you had to go to another station for gas and they had no free air; and the third station had to get water out of the spring back of the house — but why prolong the agony.

The same thing applies to the heat-treating room. Have you guessed it? Good! Write to the N. E. H. T. S. Co., and put ALL your heat-treating propositions up to them. ALL will be taken care of — they represent —

American Gas Furnace Co. — Rodman Chemical Co.
Wilson - Maeulen Co. — Duraloy Co.

NEW ENGLAND HEAT-TREATING SERVICE CO., Inc.
112 High St., Hartford, Conn.



Carbonizing Boxes

Nickel Alloy — A high nickel chromium alloy. Low first cost—long lived. Reasonable scrap allowance.

Special Alloy Steel — Boxes made of this special alloy will last longer than ordinary steel boxes and the cost is no higher.

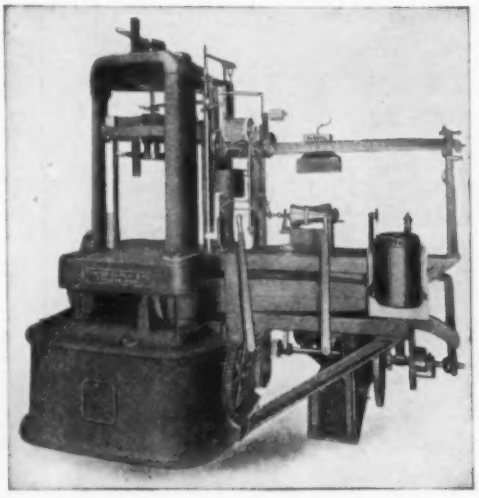
Miscellaneous Castings

As we have complete foundry facilities we are in a position to furnish you with castings made either of Steel or Nickel Alloy.

Swedish Crucible Steel Co.

Detroit, Mich.

OLSEN TESTING MACHINES



Olsen Latest Automatic and Autographic Universal Testing Machine

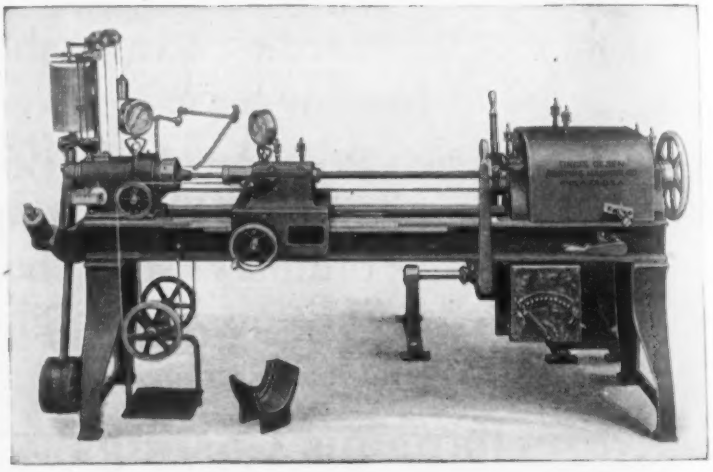
Ductility or Sheet Metal Testing Machines
Torsion Testing Machines
Brinell Hardness Testing Machines
Herbert Pendulum Hardness Tester
Impact Testing Machines
Alternate Stress Testing Machines
Spring Testing Machines
Oil, Grease and Bearing Metal Testing Machines
Strain Gauges, Extensometers and Instruments

KNOWLEDGE IS POWER

(For determining the cutting property of drills, taps, dies, reamers, cuting compounds, files, hacksaw blades and milling cutters. Also tool-steel and metals.)

The advancement in the art of making high speed cutting steel and the ever increasing use of special cutting tools of such steel have necessitated the development of this unique testing machine for determining their cutting quality.

It has been determined that various tool steels should be operated at a definite speed for maximum efficiency, depending on their treatment and the material they are to cut. The shape of such tools also are of the utmost importance, as slight variations in angle or clearance of cutting edges may cause a variation of several hundred per cent in production.



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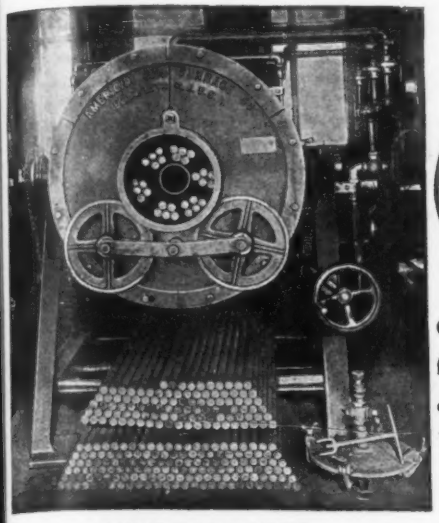

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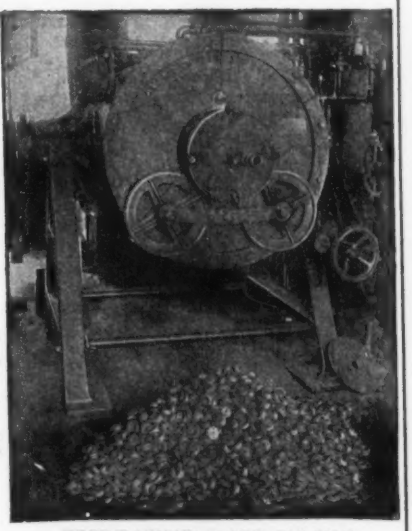

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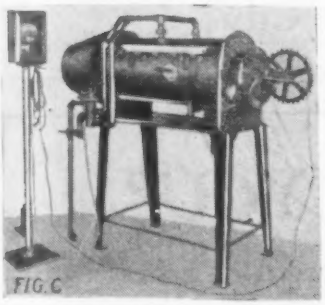

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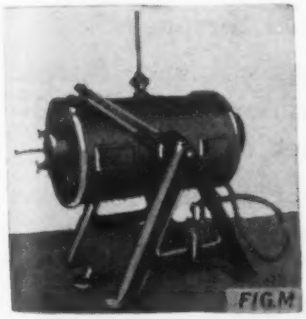

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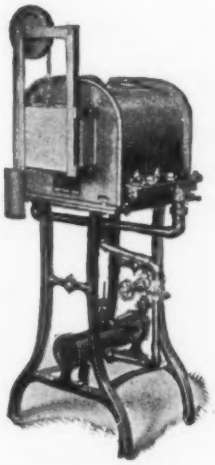

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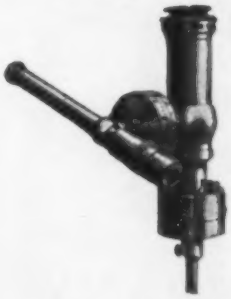

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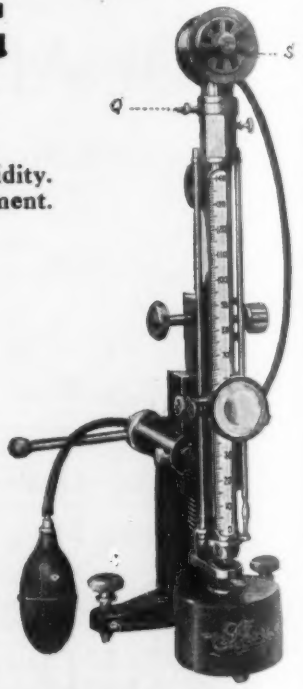

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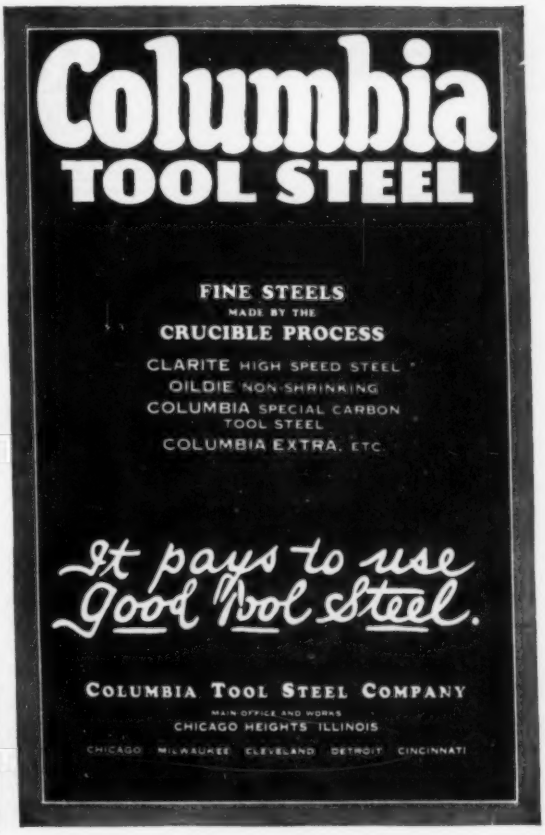

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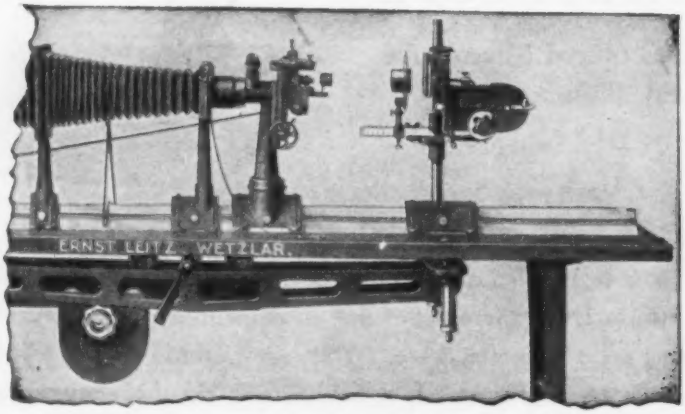

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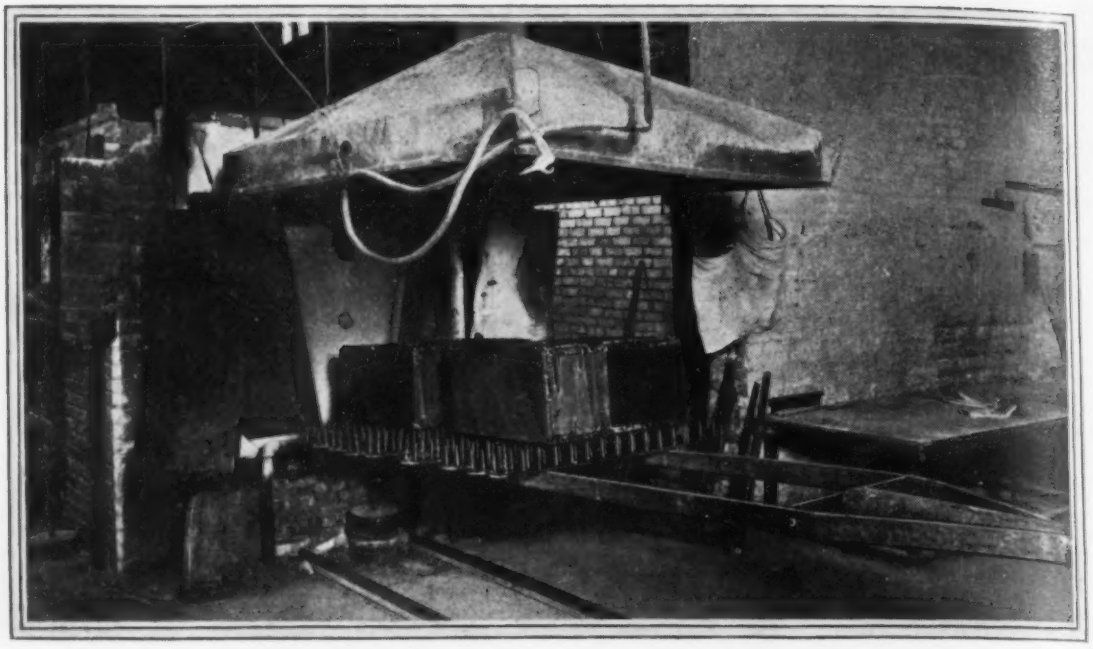

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PHILADELPHIA CHICAGO CLEVELAND
DETROIT SAN FRANCISCO LOS ANGELES

ENGELHARD PYROMETERS

SPECIFICATIONS
TYPE "S" RECORDER

SIZE:
Case is 18" high, 14" wide, 10½" deep.

CHART:
Calibrated width is 5¼".

SWITCH:
Platinum electrodes, mercury contacts.

CAPACITY:
Single and 2, 3, 4 and 6 records.

RECORD:
On top of chart. Instantly visible.

RE-ROLL:
Chart is automatically re-rolled.

CASE:
Totally dust and fume proof.

OPERATION:
From 110 to 220 volt A. C. or D. C. circuits.

Bulletin 34-S

CHARLES ENGELHARD, INC.
30 CHURCH ST.,
NEW YORK CITY